PB-214 892

OHIO RIVER POLLUTION SURVEY: ACID MINE DRAINAGE STUDIES

Public Health Service
Cincinnati, Ohio

1942

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ACID MINE DRAINAGE STUDIES

Supplement "C" to
Final Report to the Ohio River Committee
Ohio River Pollution Survey

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FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
CINCINNATI, OHIO
1942

Details of illustrations in
this document may be better
studied on microfiche.

I

ACID MINE DRAINAGE STUDIES

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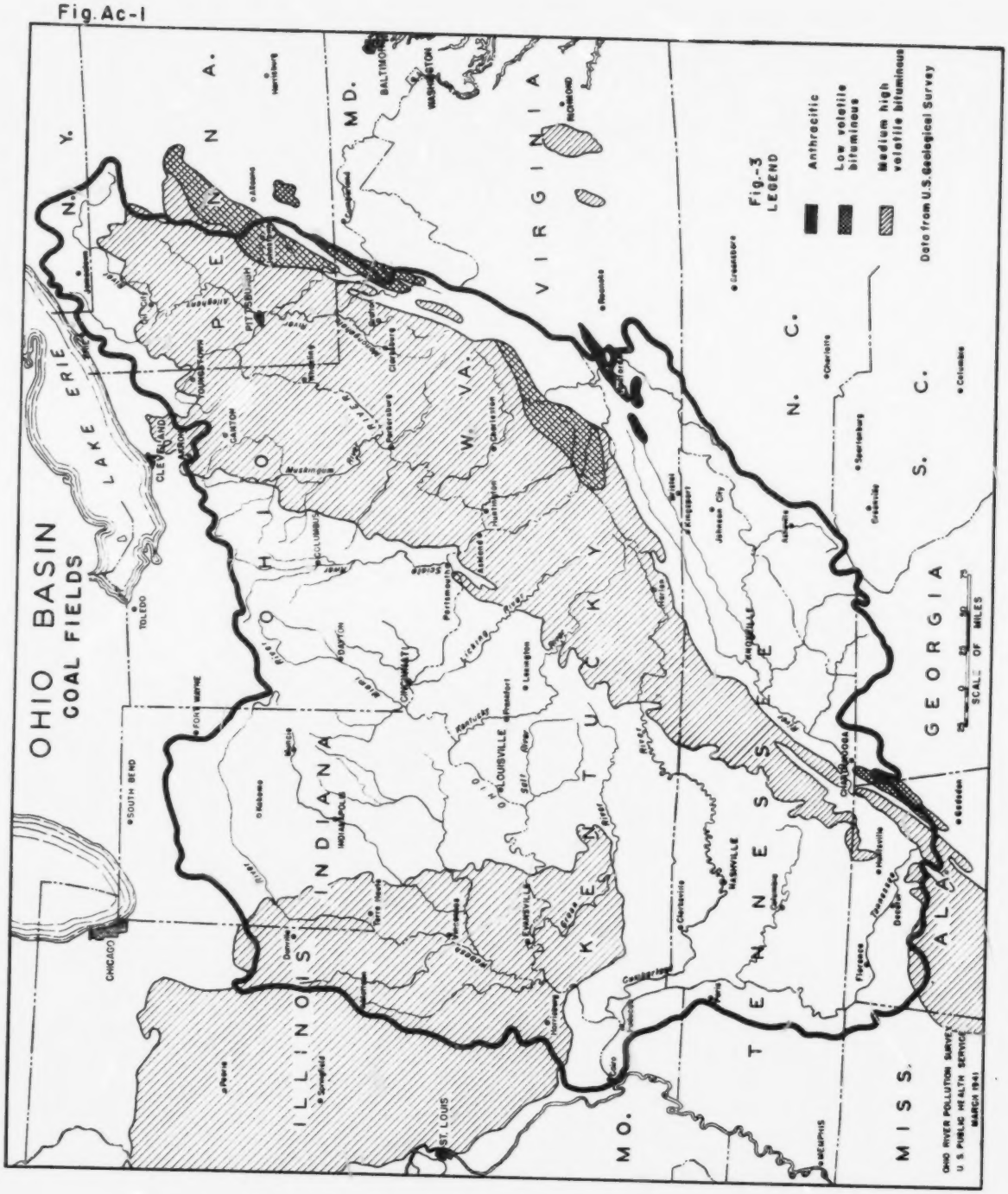
Fig. Ac-1


OHIO BASIN
COAL FIELDS
Fig.-3
LEGEND
Anthracitic
Low volatile bituminous
Medium high volatile bituminous
Data from U.S. Geological Survey
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
MARCH 1941
LAKE ERIE
PENNA.
OHIO
W. VA.
VIRGINIA
MD.
N. Y.
KY.
TENNESSEE
N. C.
S. C.
GEORGIA
ALA.
MISS.
MO.
ILLINOIS
INDIANA
CHICAGO
TOLEDO
CLEVELAND
PITTSBURGH
CINCINNATI
LOUISVILLE
NASHVILLE
MEMPHIS
ST. LOUIS

Introduction

Consideration of the acid mine drainage problem by the Ohio River Pollution Survey has been largely through the assembly and analysis of existing data. In this connection, the assistance of the Office of Mine Sealing, U. S. Public Health Service is deserving of special mention. Records accumulated by that office, working with the Works Progress Administration over a period of eight years, proved to be of great value.

Certain field studies were undertaken. A laboratory unit, stationed at Morgantown, West Virginia, conducted a study of Deckers Creek during the latter half of 1940 and the first half of 1941. In addition, the effect of acid mine drainage is reflected in the results from the regular comprehensive stream sampling program conducted throughout the Ohio River Basin.

A section of the Main Report of the Ohio River Pollution Survey has been devoted to the problem of acid mine drainage and that section with new table and figure numbers is included in this supplement as a summary and one of five general subdivisions into which this presentation is divided, as follows:

Summary for Main Report includes acid loads, costs and acid reduction by mine sealing, features of a mine acid control program and summarized details of such a program for the upper Ohio River Basin.

General Features including history and magnitude of the coal mining industry; types of mines, cause of acid formation, theory and practice of remedial measures and legal features including State and Federal statutes and court decisions.

Presentation of Field Data including present acid load and its distribution in as much detail as the data warrants, the status of present remedial measures, the effects of acid mine drainage and the type, extent and magnitude of damages caused.

Presentation of Laboratory Data making reference to the Morgantown, West Virginia, and regular sampling results. Mention is made of stream quality trends over a period of years as indicated by water plant records.

Discussion including presentation of a suggested comprehensive program to control acid pollution by further mine sealing and the use of flow regulation. Estimates of cost are included, together with financial justification for the program. The suggested program of acid pollution control is correlated with a parallel program of organic pollution control.

Summary for Main Report

Acid drainage from coal mines affects the streams throughout the area covered by the Ohio River Basin coal fields, (see Figure Ac-1). In Pennsylvania and West Virginia, the two largest bituminous coal producing states, the problem dominates the stream sanitation picture. The present situation exists despite the fact that in these two states only 5.1 percent of the coal deposit has been mined out or lost. The present survey has conducted a study of the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Particular attention has been directed to control measures involving mine sealing and flow regulation, particularly by multiple purpose use of flood-control and other purpose reservoirs. Studies and demonstrations by the U. S. Bureau of Mines of the possible accomplishments of mine sealing have shown that acid control at the mine is practical at reasonable cost, and a start, made in the form of a Works Progress Administration program (see Figure Ac-2) of sealing abandoned mines with U. S. Public Health Service and State cooperation, has confirmed (see Figure Ac-3) the earlier work. The present sealing program, however, is not a continuing activity having been discontinued from time to time in some states. Provision for essential maintenance is lacking. Flow regulation by flood-control reservoirs built by the U. S. Engineer Department has had a beneficial effect. Aggressive prosecution of a suggested remedial program is amply justified, particularly in the Pittsburgh District where tangible monetary benefits can be shown in excess of remedial costs. Remedial measures are imperative to insure the future of the principal streams in the mining areas.

Acid Load Reduction by Sealing

Mine acid loads in the major tributaries of the Ohio River Basin as originally measured and after present sealing and suggested sealing under 1940 restrictions are given on Figure Ac-2 and Table Ac-1. Total basin acid loads from this table and the estimated load following a sealing program with 1940 restrictions modified are as follows:

Original mine acid load	2,500,000	Tons	per	year
Reduction, to date, by sealing	700,000	"	"	"
Present mine acid load	1,800,000	"	"	"
Possible further reduction by sealing under 1940 restrictions	600,000	"	"	"
Load after sealing under 1940 restrictions	1,200,000	"	"	"
Possible further reduction with 1940 restrictions modified	600,000	"	"	"
Estimated ultimate residual load	600,000	"	"	"

The sealing program under 1940 restrictions is based on a cost limitation of $10.00 per ton of acid per year and sealing only in areas not connected to active ventilation systems. Modified restrictions would permit sealing operations in worked-out sections of active mines.

The cost and benefit estimates, discussed later, apply to work necessary to complete a sealing program under 1940 restrictions and the report discusses this completion as a first objective.

Free mineral acid from waste pickle liquor is estimated at 3.4 percent (see Table Ac-8) of the present total free and combined mine acid load. Acid from hydrolized iron sulphates may be minor or as high as 10 times this quantity depending on the hydrolysis equilibrium.

Mine Sealing Costs

Mine sealing costs to date in the Ohio River Basin, as shown in Table Ac-2, have been about $5,400,000. To complete a sealing program under 1940 restrictions will cost an estimated additional $5,500,000. Annual charges of interest (3½%), amortization (0.7% based on 3½% interest and a 50 year life), inspection (2%) and maintenance (7 to 10%) are about 15 percent or $1,635,000 on the total of these two sums of $10,900,000. This is about 4 mills per net ton of production and confirms an estimate of the Office of Mine Sealing, U. S. Public Health Service. These and other estimates of future mine sealing costs are believed conservatively high as they are based primarily on past experience with Works Progress Administration programs with the dual purpose of providing relief and improving mine acid conditions.

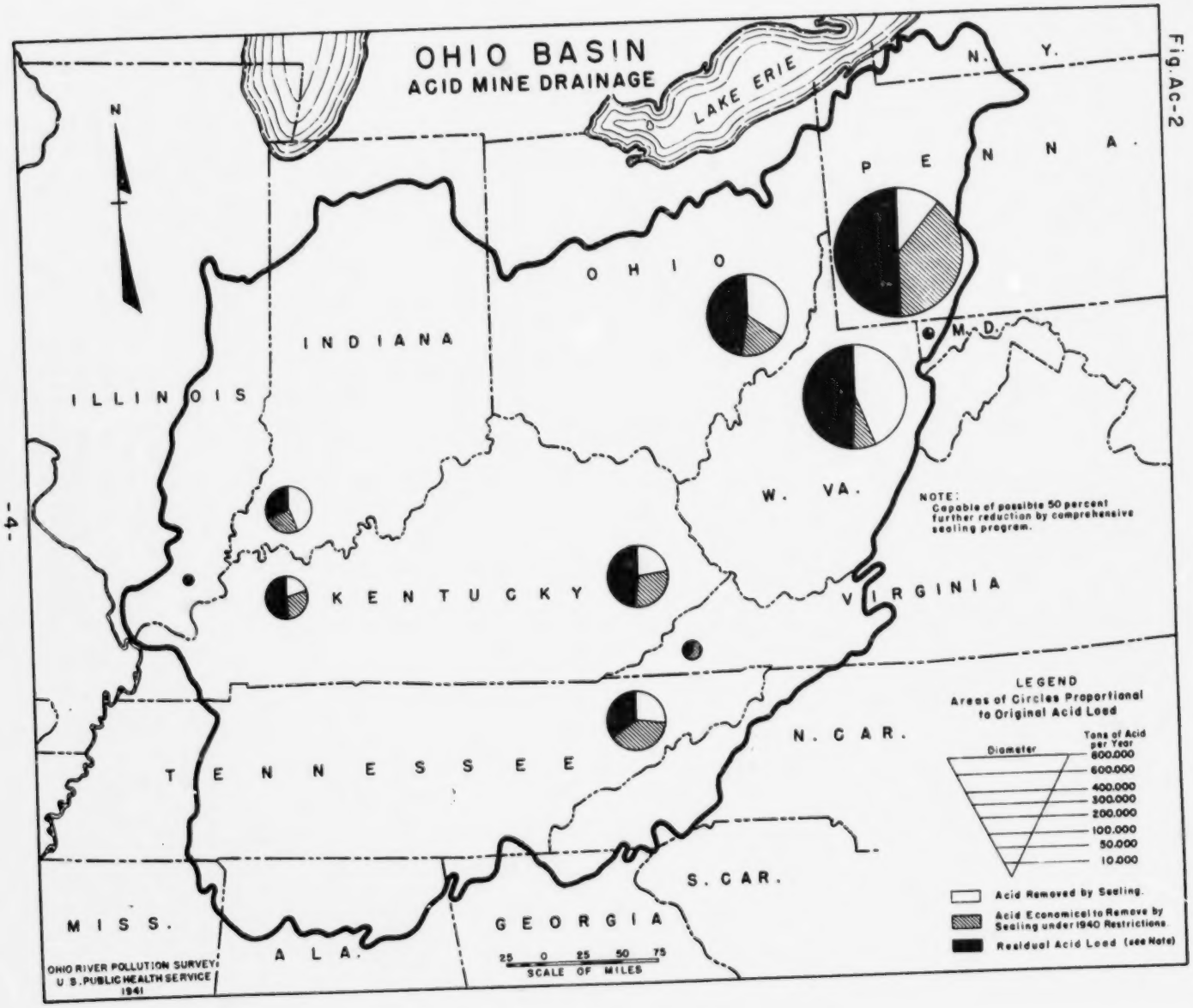

OHIO BASIN
ACID MINE DRAINAGE
LAKE ERIE
N. Y.
PENNA.
OHIO
INDIANA
ILLINOIS
M. D.
W. VA.
KENTUCKY
VIRGINIA
TENNESSEE
N. CAR.
S. CAR.
GEORGIA
MISS.
ALA.
N
NOTE:
Capable of possible 50 percent further reduction by comprehensive sealing program.
LEGEND
Areas of Circles Proportional to Original Acid Load
Diameter
Tons of Acid per Year
800,000
600,000
400,000
300,000
200,000
100,000
50,000
10,000
Acid Removed by Sealing.
Acid Economical to Remove by Sealing under 1940 Restrictions.
Residual Acid Load (see Note)
25 0 25 50 75
SCALE OF MILES
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Fig. Ac-2

Table Ac-1 Acid Mine Drainage - Summary by Tributary Drainage Basins and States of Original Classified Mine Acid Loads, Intensity per Square Mile, Acid Removed by Sealing, Estimated Acid Economical to Remove under 1940 Restrictions and Residual Mine Acid Loads.

Tributary Drainage Basin and State	Drainage Area	Original Acid Load as $CaCO_3$					Sealed Mines		Acid Removed by Sealing	Present Acid Load	Economical to Remove in Addition By Sealing	Residual Acid Load After Sealing under 1940 Restrictions (2)	
		Active Mines	Marginal (1) Mines	Abandoned Mines	Total Mines		Original Acid Load	Efficiency					
	Square Miles	Tons per Year			Tons per Year	Tons per Sq.Mi. per Year	Tons per Year	Percent	Tons per Year				Percent
Minor Tributary Basins - Pa.	1,290	27,380	11,320	10,697	49,397	38.3	14,100	64	9,030	40,367	15,050	25,317	51
Ohio	6,450	21,100	7,400	85,000	113,500	17.6	45,820	54	24,750	88,750	40,200	48,550	43
W.Va.	3,005	7,579	764	18,464	26,807	8.9	14,028	65	9,120	17,687	1,770	15,917	59
Ky.	5,680	4,700	1,300	11,200	17,200	3.0	7,854	50	3,927	13,273	4,900	8,373	49
Ind.	3,480	2,978	64	10,013	13,055	3.8	6,964	87	6,060	6,995	496	6,499	50
Ill.	1,645	356	1,804	411	2,571	1.6	305	70	214	2,357	1,000	1,357	53
Total	21,550	64,093	22,652	135,785	222,530	10.3	89,071	60	53,101	169,429	63,416	106,013	48
Alle. R. except Kiski.	9,838	26,457	6,760	50,241	83,461	8.5	24,040	78	18,750	64,711	32,330	32,380	39
Kiskiminetas River	1,892	223,896	23,805	73,988	321,689	170.0	20,270	54	10,954	310,735	132,630	178,105	55
Allegheny River Total	11,730	250,353	30,565	124,232	405,150	34.5	44,310	67	29,704	375,446	164,960	210,486	52
Monon. except Yough.	5,648	438,274	39,064	223,634	700,972	124.1	380,028	68	251,900	449,072	115,630	333,442	48
Youghiogheny River	1,732	141,735	25,609	52,240	219,604	126.8	29,270	78	22,742	196,942	83,050	113,892	52
Monongahela R. Total	7,380	580,009	64,673	275,874	920,656	124.7	409,296	67	274,642	646,014	198,680	447,334	49
Beaver River	3,145	5,480	988	10,920	17,388	5.5	5,376	42	2,280	15,108	6,500	8,608	50
Muskingum & Hocking R.	9,225	37,700	14,600	163,500	215,800	23.4	170,000	54	91,400	124,400	19,000	105,400	49
Little Kanawha River	2,320	323	2	493	818	0.4	716	65	470	348	50	298	36
Kanawha River	12,300	9,210	995	22,650	32,855	2.7	21,157	65	13,750	19,[illegible]	2,170	16,935	52
Guyandot River	1,670	15,680	614	3,890	20,184	12.1	14,333	65	9,320	10,[illegible]	1,330	9,543	47
Big Sandy River	4,280	16,236	8,997	35,699	60,932	14.2	26,324	56	14,738	46,194	18,320	27,874	46
Scioto River	6,510	4,900	2,400	16,800	24,100	3.7	11,540	54	6,230	17,870	7,100	10,770	45
Little Miami River	1,755	0	0	0	0	0	-	-	-	-	-	0	-
Licking River	3,670	-	-	-	Slight	-	-	-	-	-	-	0	-
Miami River	5,385	0	0	0	0	0	-	-	-	-	-	0	-
Kentucky River	6,940	10,900	3,200	27,800	41,900	6.0	22,865	50	11,433	30,467	9,520	20,947	50
Salt River	2,850	0	0	0	0	0	-	-	-	-	-	0	-
Green River	9,220	26,500	7,900	42,100	76,500	8.3	30,230	50	15,115	61,385	23,140	38,245	50
Wabash River	33,100	26,777	3,174	79,631	109,582	3.3	54,054	87	47,040	62,542	30,403	32,139	29
Saline River	1,235	-	-	-	Slight	-	-	-	-	-	-	0	-
Tradewater River	995	3,000	1,500	3,400	7,900	7.9	1,730	50	865	7,035	3,270	3,765	48
Cumberland River	18,000	53,610	13,045	198,115	264,770	14.7	105,066	65	68,862	195,908	93,070	102,838	39
Tennessee River	40,600	4,960	1,145	32,063	38,168	0.9	20,239	80	16,200	21,968	10,770	11,198	29
Unclassified - Va.	7,175	-	-	-	18,750	2.6	0	-	0	18,750	11,070	7,680	41
TOTAL	203,900	1,109,731	176,450	1,173,052	2,477,983	12.2	1,026,288	64	655,150	1822833	662,769	1,160,064	47
Alabama	6,810	0	0	0	0	0	-	-	-	-	-	0	-
Georgia	1,490	0	0	0	0	0	-	-	-	-	-	0	-
Illinois	11,440	356	1,804	411	2,571	0.2	305	70	214	2,357	1,000	1,357	53
Indiana	29,135	29,775	3,233	89,644	122,637	4.2	61,018	87	53,100	69,537	30,899	38,638	32
Kentucky	29,375	88,900	31,700	180,000	300,600	7.6	129,000	50	64,500	236,100	89,500	146,600	49
Maryland	430	535	79	847	1,461	3.4	570	60	342	1,119	400	719	49
Mississippi	385	0	0	0	0	0	-	-	-	-	-	0	-
New York	1,955	0	0	0	0	0	-	-	-	-	-	0	-
North Carolina	6,260	0	0	0	0	0	-	-	-	-	-	0	-
Ohio	29,570	65,000	25,000	270,000	360,000	12.2	229,600	64	123,590	236,410	68,900	167,510	46
Pennsylvania	15,620	521,513	90,003	277,833	889,349	56.9	128,237	72	91,804	797,545	349,560	447,985	50
Tennessee	33,645	25,170	5,190	160,478	190,838	5.7	74,771	80	59,800	131,038	72,440	58,598	31
Virginia (Unclassified)	7,175	-	-	-	19,750	2.6	0	-	0	18,750	11,070	7,680	41
West Virginia	20,610	378,502	19,436	193,839	591,777	28.7	402,787	65	261,800	329,977	39,000	290,977	49
TOTAL	203,900	1,109,731	176,450	1,173,052	2,477,983	12.2	1,026,288	64	655,150	1822833	662,769	1,160,064	47

(1) Not completely abandoned. (2) Areas connected to active ventilation systems and areas where costs exceed $10 per ton per year not included.

Fig. Ac-3

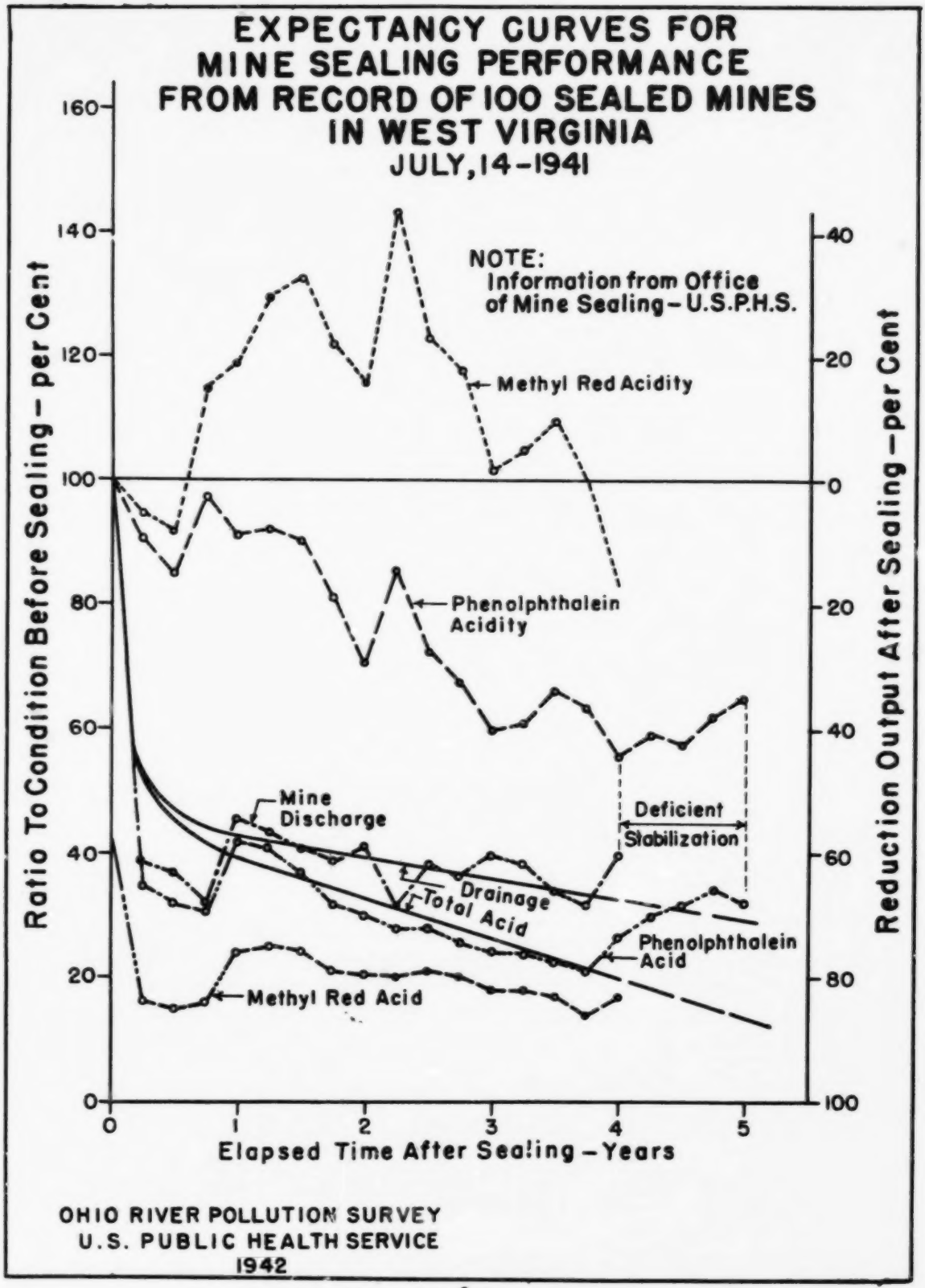

EXPECTANCY CURVES FOR
MINE SEALING PERFORMANCE
FROM RECORD OF 100 SEALED MINES
IN WEST VIRGINIA
JULY, 14-1941
NOTE:
Information from Office
of Mine Sealing - U.S.P.H.S.
Methyl Red Acidity
Phenolphthalein
Acidity
Mine
Discharge
Deficient
Stabilization
Drainage
Total Acid
Phenolphthalein
Acid
Methyl Red Acid
Ratio To Condition Before Sealing - per Cent
Reduction Output After Sealing - per Cent
Elapsed Time After Sealing - Years
160
140
120
100
80
60
40
20
0
40
20
0
20
40
60
80
100
0
1
2
3
4
5
OHIO RIVER POLLUTION SURVEY
U.S. PUBLIC HEALTH SERVICE
1942

Table Ac-2 Acid Mine Drainage - Cost of Works Progress Administration Program of Mine Sealing to Date and Estimated to Complete Restricted Mine Sealing Program, both State-wide and for the Ohio River Basin.

State	State-Wide Expenditures			Ohio Basin Expenditures	
	Total to Date (1)	Per Ton Per Yr. of Acid Sealed	Estimated to Complete Program	Estimated Total to (1) Date	Estimated to Complete Program
By States					
Illinois	$ 12,000	$ 7.26	-	(2)	-
Indiana	273,000	4.48	$ 80,000	$ 270,000	$ 80,000
Kentucky	340,000	2.66	1,200,000	340,000	1,200,000
Maryland	221,000	8.25	50,000	10,000	-
Ohio	1,935,000	8.40	400,000	1,940,000	400,000
Penn.	2,666,000	11.50	4,000,000	1,490,000	3,100,000
Tennessee	109,000	2.46	420,000	110,000	420,000
Virginia	0	-	150,000	0	150,000
W.Virginia	1,462,000	3.00	200,000	1,210,000	160,000
Total	7,018,000	5.80	6,500,000	5,370,000	5,510,000
By Basins					
Minor Tributary Basins				$ 650,000	$ 480,000
Allegheny				510,000	1,460,000
Monongahela				1,820,000	1,600,000
Beaver				60,000	50,000
Muskingum and Hocking				1,450,000	110,000
Kanawha				70,000	120,000
Guyandot				40,000	10,000
Big Sandy				70,000	240,000
Scioto				100,000	40,000
Kentucky				60,000	130,000
Green				80,000	310,000
Wabash				240,000	80,000
Cumberland				200,000	780,000
Tennessee				20,000	100,000
Total				5,370,000	5,510,000

(1) Rounded. (2) Less than 5,000.

Mine Acid Control Program

Present information indicates that correction, in large measure, of the mine acid pollution problem is practical by a comprehensive control program involving the following measures:

(a) Provision for the inspection and maintenance of present air seals and a similar provision in connection with all future mine sealing programs.

(b) Completion of the present limited (1940 restrictions) mine sealing program.

(c) Provision of reservoir capacity, presumably in primarily flood-control reservoirs, for flow regulation for acid and organic pollution control.

(d) Inauguration of an aggressive program of mine sealing with present restrictions modified.

(e) Adaptation of the better mining methods to acid control.

(f) Extension of the established practice of refraining from discharging acid waters to streams previously uncontaminated.

(g) Clarification of the laws governing mine drainage to facilitate the corrective program.

Upper Ohio Basin

For illustrative purposes and to indicate cost to benefit relationships, special studies have been made in the upper Ohio River Basin area or the area above the Ohio-West Virginia-Pennsylvania State line. Estimates have been made of accomplishments, costs and benefits resulting from application of the first three of these items, namely, mine sealing, maintenanc and flow regulation. Any study of reservoir development should include consideration of organic pollution control and the program studied considers both organic and acid pollution.

Damages - Damages capable of monetary evaluation caused by acid mine drainage include neutralization and softening costs to domestic and industrial water supplies and corrosion of steamboats, barges, power plant condensers and river and harbor structures. These damages in the area above the Ohio-West

Virginia-Pennsylvania State line, totaling about $2,000,000 per year, are shown on Table Ac-3. Equally important, but intangible or unevaluated, damages are to water supply due to manganese, to recreation through the destruction of normal aquatic life, to agricultural uses, to highway structures, to the mines themselves, and indeterminate but serious damages to the public health due to rapid fluctuations in quality as reported by water plant operators. Mine acid is a deterrent to organic pollution abatement, as incentive for abatement measures is lacking if the result is a stream suitable only for disposal of mine waters. Mine acid is not a safeguard to public water supplies as the rapid increase in flow during a freshet may bring sufficient alkalinity to neutralize the acidity and eliminate any germicidal effect there may be.

Table Ac-3 Acid Mine Drainage - Summary, as of 1940, of Annual Damages, Capable of Accurate Estimation and Caused by Acid Mine Drainage above the Ohio-West Virginia-Pennsylvania State Line.

		Total Annual Damages
Domestic Water Supplies		$ 364,000
Industrial Water Supplies		407,000
Steamboats and Barges		1,143,000
Power Plants		76,000
River and Harbor Structures		76,000
Floating Plant (U.S.E.D.)		5,000
Total - 1940		2,071,000
Future Estimate - 1950	Based on estimated future quality but	2,630,000
Future Estimate - 1960	no increase in use	$3,190,000

Mine Sealing - Data on mine acid loads before and after various stages of sealing, similar to that given on Table Ac-1 for the upper Ohio River Basin are as follows:

Original mine acid load	1,375,000	Tons per year
Reduction, to date, by sealing	313,000	" " "
Present mine acid load	1,062,000	" " "
Possible further reduction by sealing under 1940 restrictions	379,000	" " "
Load after sealing under 1940 restrictions	683,000	" " "

The completion of a mine sealing program in this area under 1940 restrictions will cost an estimated $3,250,000. Annual charges, including interest, amortization, inspection and maintenance as already enumerated, are 15 percent or $488,000 on this expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000 per year, making a total of $870,000 per year. As shown on Figure Ac-3 if these existing seals are not maintained, the benefits already realized may easily be lost making it necessary to repeat the expenditure.

Flow Regulation - The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity but there will still remain acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage. The estimated reservoirs selected for acid control are the largest that can be used without storing for periods greater than one year. Utilization of increased capacity beyond this point would be infrequent and the unit value would therefore be reduced. Reservoir capacities selected in the upper Ohio River Basin area under these conditions are as follows:

Allegheny Basin	210,000	Acre-feet
Monongahela Basin	370,000	" "
Total	580,000	" "

Organic pollution in the upper main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 c.f.s. during the warm summer months (25°C. or 77°F. average monthly air temperature) and progressively lesser flows as temperatures decrease. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drouth occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drouth. A valuable partial organic pollution control would be available during a year such as 1930.

Storage required for organic pollution abatement is 430,000 acre-feet (except in 1930) while total storage selected for acid control is 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Benefits and Costs - Benefits of the combined program due to acid control are due to a reduction in the damages detailed on Table Ac-3. Benefits to organic pollution control are due to a reduction in the cost of needed sewage and industrial waste treatment.

Reduction in maximum monthly acidities equitably assigned to the two items; mine sealing and flow regulation, of this program are as follows:

	Acidity (1) - P.P.M.	
	Allegheny at Aspinwall	Monongahela abv. McKeesport
Present monthly maximum	23	33
Reduction by sealing (2)	22	19
Reduction by reservoirs (2)	14	10
Resulting monthly maximum	(3)	4

(1) To Methyl Red on Allegheny and Methyl Orange on Monongahela.
(2) Equitably assigned or average improvement if remedy applied constructed first or second. As a rule, projects applied first show increased benefits at expense of later projects.
(3) 13 p.p.m. minimum alkalinity.

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela and upper Ohio River Basin due to the suggested mine sealing and flow regulation programs total $1,133,000 per year. This estimate is believed conservative as it is based on 1940 damages instead of greater possible future damages and it does not include benefits to unevaluated and intangible items. Deducting the cost of sealing of $870,000 per year from these benefits leaves $263,000 per year that can be spent on reservoir construction for acid and hardness reduction.

In correcting sewage and organic industrial waste pollution without flow regulation, a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is $300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional $300,000.

While the flow regulation is designed primarily for acid pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a valuable aid in organic pollution control. The two flow regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic pollution control. An examination of flow and acidity records indicates that acid control and organic pollution abatement can both be accomplished with the exception of one month (also excepting 1930) in ten years and this accomplishment has been taken as satisfactory.

Annual benefits to flow regulation include $263,000 left after deducting mine sealing costs from acid and hardness control benefits, plus $300,000 for organic pollution control at Pittsburgh and $300,000 for organic pollution control benefits at Cincinnati, making a total of $863,000 per year. For a storage of 580,000 acre-feet, the annual benefits or the amount that can be economically spent per acre-foot per year is $1.49.

A summary of the cost and benefit relation is as follows:

	Annual Benefits and Costs
Benefits - Acid Control	$1,133,000
Cost - Mine Sealing To date and Future	870,000
Balance - Acid Control for Reservoirs	263,000
Benefits - Organic Pollution Control	
Pittsburgh	300,000
Cincinnati	300,000
Total available for reservoirs	$863,000
Per Acre-Foot	$1.49

Reservoir benefits are, in large measure, due to equalizing and surge reducing effects following mine sealing in order to develop full benefits from the sealing program. The balance for reservoirs indicated is, therefore, available to the extent shown only if and when the mine sealing program is assured. Mine sealing, on the other hand, can be justified beyond reasonable doubt as a single independent remedial measure.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-Upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

General Features

History of Industry

The history of the acid mine drainage problem parallels the history of the industry and there are certain general features of the industry which have a marked influence and must be considered in any study of the acid problem.

Coal mining in the United States and in the Ohio Basin has reached its present magnitude within the last 25 years and the acid mine drainage problem has become increasingly acute during that time. The industry is large in itself and is vital to all industrial activity in its area. The coal mining industry, through its drainage, damages a prosperous area at the same time that it is largely responsible for the very existence of the prosperity of that area. Location and area of the Ohio Basin coal fields are shown on Figure Ac-1.

Early Development - The first recorded production of coal was in 1750 when 5[illegible] tons were mined in Virginia. There was no other important production until 1759 when a coal mine was opened on the Monongahela River opposite Fort Pitt, now Pittsburgh. In 1793 the United States produced about 63,000 tons of coal which was mined mainly in Pennsylvania and West Virginia. In 1840 when the first Federal census was taken coal production was approximately 2,000,000 tons. From 1841 to 1869 annual production grew to about 15,000,000 tons. From 1841 to 1869, except for 1865, Pennsylvania anthracite production exceeded total bituminous production. Since then bituminous production has been greater. Until 1873 imports exceeded exports but since there has been a considerable export balance.

Recent Trends - In the period, roughly 1890 to 1920, coal mining was one of the nation's most rapidly growing industries. Production approximately doubled every 8 to 10 years but following the first world war peak, reached in 1918, the general long-time trend has been downward. Reasons for this downward trend are believed to be: (1) slower growth of population and industry, (2) fuel economy resulting from better burning equipment and careful combustion control, (3) competing fuels mainly oil and gas. In 1900 coal contributed 89% of the energy derived from the mineral fuels (coal, oil and gas) and water power. By 1937 this had dropped to 54%. Natural gas and petroleum contributed 43% and water power 3%. In general, the coal industry has been losing ground in most of the postwar period.

Present Magnitude

The annual value of coal production in five states exceeds the value of the entire annual national output of gold, silver, copper, lead, zinc and aluminum. In West Virginia the number of men employed by coal mines exceeds the total supported by manufacturing industries and in Kentucky the number is not much less. In Pennsylvania the bituminous coal mines normally employ more men than the steel industry.

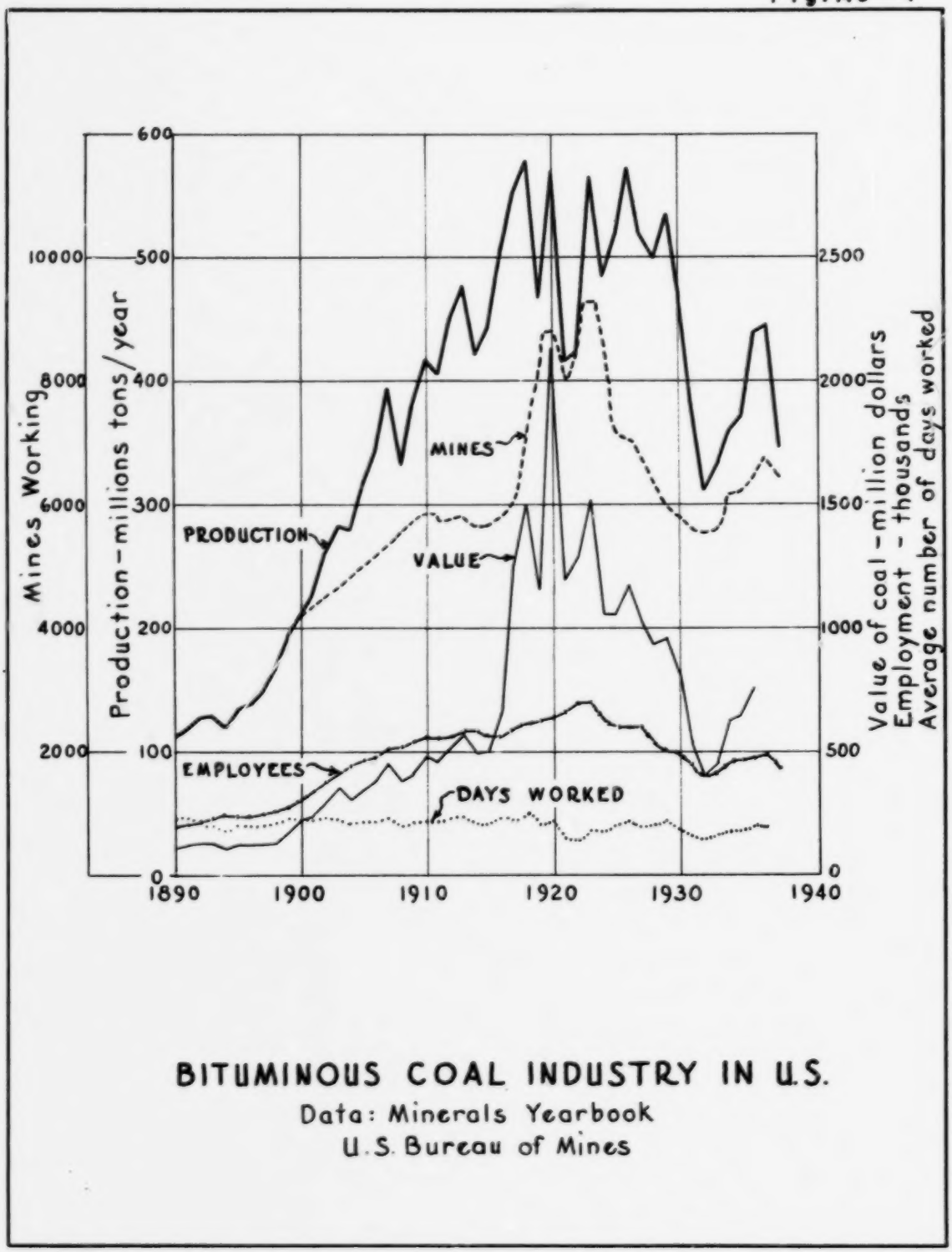
The coal industry is a large power consumer and spends large sums annually for machinery, tools, timber, etc. In 1935 the industry's power bill was about $25,000,000.00 and approximately $75,000,000.00 were spent for supplies and equipment. Investment in the industry is estimated to be of the order of three billion dollars with the bituminous coal mining investment at from 2 to 2.5 billion dollars. In Pennsylvania in 1929 the investment was approximately 500 million dollars.

In 1923 the average number of men employed at operating mines including the anthracite districts was 862,536, in 1929, 654,444, in 1937, 585,500. The value at the mines of the coal produced was $1,338,000,000 in 1929 and $960,000,000 in 1937. In prosperous years coal has constituted as much as 35% of the total railroad freight tonnage, corresponding to 23% of the railroad freight revenue.

Table Ac-4 and Figure Ac-4 present information on the growth since 1890 and the present magnitude of the coal industry in terms of annual net tons production, value of product, employees, days worked and number of mines in operation.

Table Ac-5 shows total coal resources and the maximum coal production by Ohio Basin states.

Fig. Ac – 4



BITUMINOUS COAL INDUSTRY IN U.S.

Data: Minerals Yearbook
U.S. Bureau of Mines

Table Ac-4 Acid Mine Drainage - Statistics of U. S. Bituminous Coal Industry.
(From Minerals Year Book - 1938)

	Production Millions of Net Tons	Value Millions of Dollars	Men Employed (1000's)	Ave. No. Days Worked	Days lost on acct. strikes	Value per Ton (Dollars)	Net Tons per man day	% Cut by Machine	Mined by Stripping Mil. Net Tons
1890	111	110	192	226		0.99	2.56	-	
91	118	117	206	223		.99	2.57	5.3	
92	127	125	213	219		.99	2.72	-	
93	128	123	230	204		.96	2.73	-	
94	119	108	245	171		.91	2.84	-	
95	135	116	240	194		.86	2.90	-	
96	138	115	244	192		.83	2.94	11.9	
97	148	120	248	196		.81	3.04	15.3	
98	167	133	256	211		.80	3.09	19.5	
99	193	168	271	234	8	.87	3.05	22.7	
1900	212	221	304	234	5	1.04	2.92	24.9	
01	226	236	340	225	2	1.05	2.94	25.6	
02	260	291	370	230	7	1.12	3.06	26.8	
03	283	352	416	225	3	1.24	3.02	27.6	
04	279	306	438	202	8	1.10	3.15	28.2	
05	315	335	461	211	2	1.06	3.24	32.8	
06	343	381	478	213	28	1.11	3.36	34.7	
07	395	451	513	234	1	1.14	3.29	35.1	
08	333	374	516	193	11	1.12	3.34	37.0	
09	380	405	543	209	1	1.07	-	37.5	
1910	417	469	556	217	35	1.12	3.46	41.7	
11	406	451	550	211	2	1.11	3.50	43.9	
12	450	518	549	223	10	1.15	3.68	46.8	
13	478	565	572	232	5	1.18	3.61	50.7	
14	423	493	584	195	19	1.17	3.71	51.7	1.3
15	443	502	557	203	4	1.13	3.91	55.0	2.8
16	503	665	561	230	4	1.32	3.90	56.5	3.9
17	552	1249	603	243	4	2.26	3.77	55.5	5.8
18	579	1492	615	249	1	2.58	3.78	55.9	8.3
19	466	1161	622	195	25	2.49	3.84	59.2	5.6
1920	569	2130	640	220	6	3.75	4.00	59.8	8.9
21	416	1200	664	149	3	2.89	4.20	65.6	4.7
22	422	1275	688	142	78	3.02	4.28	63.2	9.9
23	565	1515	705	179	2	2.68	4.47	66.9	11.8
24	484	1063	620	171	7	2.20	4.56	69.5	13.6
25	520	1060	588	195	2	2.04	4.52	70.6	16.9
26	573	1183	594	215	1	2.06	4.50	71.7	16.9
27	518	1030	594	191	45	1.99	4.55	72.2	18.4
28	501	934	522	203	8	1.86	4.73	73.8	19.8
29	535	953	503	219		1.78	4.85	75.4	20.3
1930	468	795	493	187		1.70	5.06	77.5	20.2
31	382	589	450	160	3	1.54	5.30	79.1	18.9
32	310	407	406	146		1.31	5.22	78.8	19.6
33	334	446	419	167	9	1.34	4.78	80.0	18.3
34	359	628	458	178		1.75	4.40	79.2	20.8
35	372	658	462	179		1.77	4.50		23.6
36	439	768	477	199		1.76	4.62		28.1
37	446		492	193		2.10	4.69		31.8
38	345		435			2.04			

Table Ac-5 Acid Mine Drainage - Bituminous Coal Resources as of End 1936[1] and Maximum Annual Production and Total Production by States.

State (2)	Bituminous Coal Resources					Bituminous Coal Production			
	Original Deposits	Production	Losses (3)	Reserves (4)	Mined Out and Lost	Year of Maximum Production	Maximum Annual Production	Total Production from earliest record to end 1937	Per cent of Total U.S.Production
	Millions of Net Tons (2,000 lbs.)				Per Cent		Net Tons (2,000 lbs.)		
Georgia	933	11	6	916	1.8	1903	416,000	-	-
Illinois	201,400	2,354	1,251	197,795	1.8	1918	89,291,000	2,405,891,000	12.95
Indiana	53,051	703	374	51,974	2.0	1918	30,679,000	721,091,000	3.88
Kentucky	123,327	1,163	618	121,546	1.4	1927	69,124,000	1,209,969,000	6.51
Maryland	8,043	238	127	7,678	4.5	1907	5,533,000	239,947,000	1.29
N.Carolina	68	1	1	66	2.9	1922	79,000	-	-
Ohio	93,967	1,310	696	91,961	2.1	1920	45,878,000	1,335,547,000	7.19
Penna.	112,148	5,777	3,070	103,301	7.9	1918	178,551,000	5,888,186,000	31.70
Tenn.	25,665	245	130	25,290	1.5	1910	7,121,000	250,197,000	1.35
Virginia	21,149	328	174	20,647	2.4	1926	14,133,000	349,074,000	1.88
W.Virginia	152,544	3,132	1,664	147,748	3.1	1927	145,122,000	3,250,331,000	17.50
Total	792,295	15,262	8,111	768,922	3.0	-	-	15,650,233,000 (5)	84.25

(1) From National Resources Committee Report. Energy Resources and National Policy, p.283.
(2) Includes entire State, parts of which are outside of the Ohio River Basin.
(3) Estimated average loss 34.7%
" avoidable " 19.4%
" minimum " 15.3%
(4) Therefore future recovery, 65.3 to 84.7 percent.
(5) Total bituminous coal production in U.S. from earliest record to end 1937 = 18,573,689,000 tons.

Economic Problems

The problems of the bituminous coal industry are associated with the abundance of the coal resources. This condition led to the opening of great numbers of mines and the development of excess capacity. The surplus capacity and the division of the industry into many small and large units scattered over 32 states early led to severe competition. The war (1914-1918) led to further expansion. Fuel shortages during and following the war were due to congestion and railway transport and strikes rather than lack of producing power. After 1923 the problems of surplus capacity, declining prices and competition began to be felt in intensified form and the coal industry entered a period of serious depression. From 1924 to 1929, when business in general was highly prosperous, bituminous coal mining suffered depression. The average sales realization f.o.b. mines decreased from $2.68 per ton in 1923 to $1.78 in 1929. More than 200 million tons of annual mine capacity was forced out of production and over 3,000 commercial mines were shut down or abandoned. Approximately 200,000 mine workers lost employment as a result.

The mortality rate among coal mines is notoriously high. Unfortunately, data collected do not reflect adequately this mortality because they pertain principally to the larger and more stable mining companies. It is known, however, that each year a large number of mines are abandoned, either temporarily or permanently. The U. S. Coal Commission in 1923 made a study of the probable life of certain mines. It was found that the average life expectancy of bituminous coal mines, excluding abandonment, ranged from about 12 years in some of the western mines to about 46 years in the Alabama mines. Bituminous coal mines of West Virginia reported a life expectancy of 42 years; those in Maryland, Kentucky, Virginia and Tennessee 43 years; Illinois and Indiana 32; Pennsylvania 29; and Ohio 24 years. The average age of mines studied ranged from 11 years in the western fields to about 20 years in the older eastern fields.

Following emergency regulation by the government (Food & Fuel Control Act 1917) there has been a trend toward the conviction that the coal industry's problems are not those of a temporary recession but rather problems requiring basic adjustments. The chief lines of attack have been as follows:

(1) Self-regulation by the industry.

(2) Dual regulation by the industry in cooperation with the Federal Government.

(3) Regulation under acts passed by Congress as the Conservation Act (Guffey-Snyder Coal Act) of 1935 and the Bituminous Coal Act of 1937 (Guffey-Vinson Coal Act). (The latter is now in force).

The outlook is for additional regulation in some form.

Types of Mines

Coal mines may be classified into four types based on the method of gaining access to the coal beds:

(1) Strip Mining - A limited proportion of the coal is so near the surface that the overburden of rock and dirt may be removed with power shovels leaving the coal exposed for loading into cars. Strip mining usually costs less than underground methods.

(2) Drift Mining - A tunnel is driven into the side of a hill at the coal outcrop and the coal is mined out by following the contour of the bed. This eliminates the need for driving tunnels into rocks in order to reach the coal.

(3) Slope Mines - In this type of mine tunnels on grades low enough to permit mine cars to be pulled over tracks are driven into the coal beds along which active mining is to proceed. More than half of all coal mined is taken from drift or slope mines.

(4) Shaft Mines - A vertical opening (or shaft) is driven to the coal to be mined out and mining proceeds along the coal vein from the bottom of the shaft. The average depth of shaft mines in 1926 was 262 feet. Increase in depth magnifies problems of entry, exit, ventilation, support of cover and drainage. Abandoned shaft mines are less of an acid problem than other types as, in many cases, acid discharge stops as the mine becomes flooded when mining is discontinued.

Table Ac-6 Acid Mine Drainage - Approximate Percent Distribution of Mines by Type of Opening

State	Percent			
	Shaft	Slope	Draft	Strip
Alabama	8	60	28	4
Illinois	35	38	17	10
Indiana	85	2	0	13
Kentucky	9	10	81	0
Ohio	19	20	55	6
Pennsylvania	11	13	75	1
Tennessee	10	0	90	0
West Virginia	8	8	82	2

Cause of Acid Formation

This discussion of the cause of acid formation in mines is introduced with the observation that much is yet to be learned on this subject. There are numerous instances of record where comparable mines in the same coal bed have greatly varying acid discharges and no explanation is readily apparent. In fact, serious polluting discharges are confined to less than one-half of the mines. A proper conclusion is that research is needed and this discussion points to a possible line of attack.

Hypothesis - According to a commonly advanced hypothesis, the iron, aluminum and other sulphates and sulphuric acid often found in the drainage from coal mines are formed from the pyrite, marcasite and other minerals and ores commonly found with coal deposits by the action of water and oxygen on these materials. A typical chemical reaction, using pyrite as an example of the source of sulphur, generally considered to occur, is as follows:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

Further action may then take place, in the presence of oxygen, between ferrous sulphate and sulphuric acid as follows:

$$4FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

Then: $$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + 3H_2SO_4$$

Rate of Acid Formation - There is very little information available regarding the effect of oxygen reduction in mine atmosphere on the rate of acid formation. However, this effect can be considered from a hypothetical standpoint, and certain tentative conclusions drawn.

In discussing the mechanism of the reaction involved in the natural oxidation of pyritic sulphur, Burke and Downs (Technical Publication No. 769, Trans. American Institute of Mining and Metallurgical Engineers) propose the hypothesis that the observed phenomena of oxidation are probably the result of two consecutive reactions as follows:

$$FeS_2 + 3O_2 \longrightarrow FeSO_4 + SO_2 \qquad (1)$$

$$2SO_2 + O_2 + 2H_2O \longrightarrow 2H_2SO_4 \qquad (2)$$

The sum of these two reactions, properly balanced, is the conventional reaction:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4 \qquad (3)$$

It was further assumed by Burke and Downes that the rate of reaction (1) was extremely slow as compared to the rate of (2) and that as a consequence reaction (1) determined the rate of oxidation of the pyritic sulphur.

These assumptions were all tested experimentally and the experimental evidence confirmed the theory proposed.

Since all evidence points to the equation:

$$FeS_2 + 3O_2 \longrightarrow FeSO_4 + SO_2$$

as the controlling reaction, it should be possible to generalize the rate of this reaction, and hence the rate of acid production in terms of the concentrations of the reacting substances, FeS_2 and O_2.

According to the law of mass action, the velocity of a reaction is proportional at any moment to the molecular concentrations of the reacting components and to a constant (K) which is characteristic of the chemical nature of the reacting substances and to the temperature. At any given temperature, therefore, we may write for the oxidation of pyritic sulphur:

$$V = K (FeS_2) (O_2)^3 \qquad (4)$$

V = reaction velocity

FeS_2 = pyrite concentration

O_2 = oxygen concentration

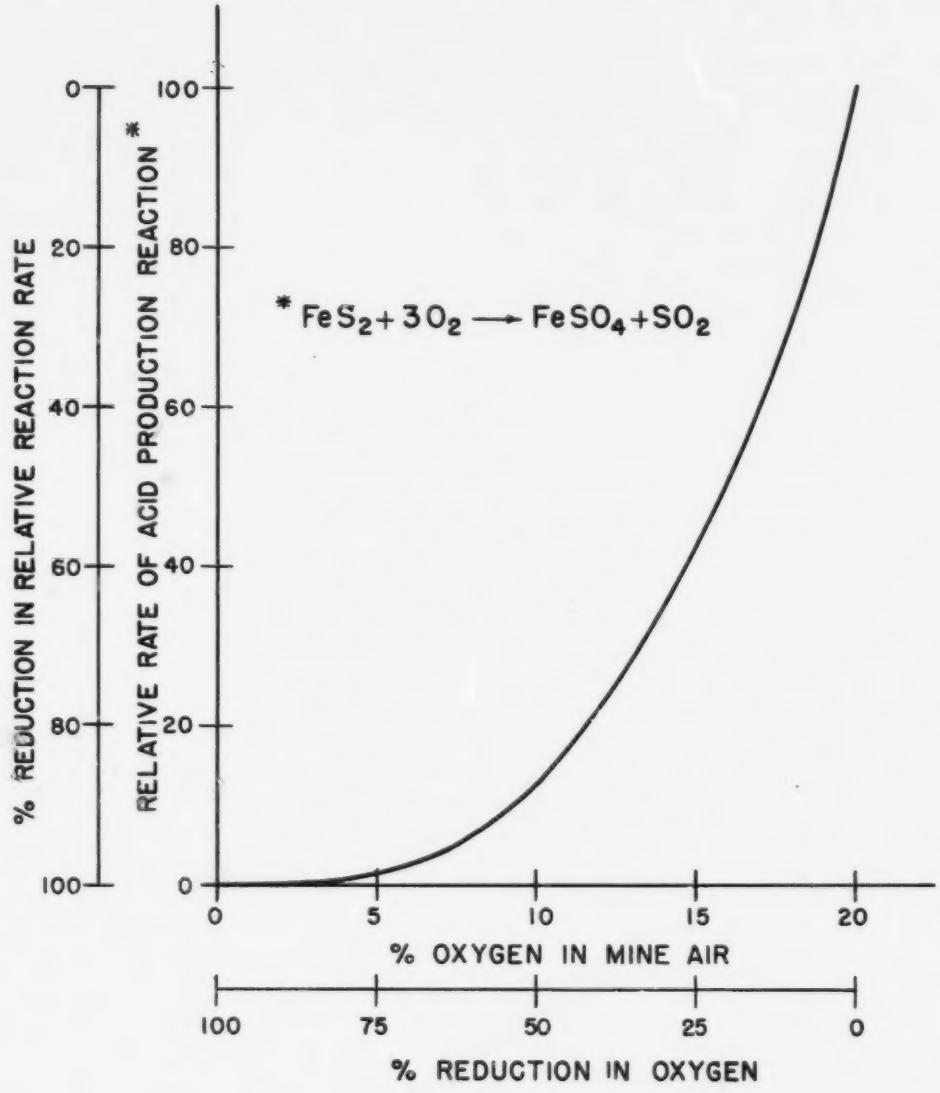
Since the amount of pyrite and other sources of sulphur available for reaction is large, its concentration may be considered to remain unchanged. Hence we may write -

$$V = K (O_2)^3 \qquad (5)$$

If the basic assumptions are correct, the above equation (5) indicates that the rate of reaction (1) which governs the rate of acid formation is proportional to the cube of the oxygen concentration. From analytical examination of the equation or reference to the graphical representation, it is evident that a small reduction in oxygen produces a proportionally far greater

Fig. Ac – 5

THEORETICAL RELATIONSHIP BETWEEN OXYGEN CONCENTRATION IN MINE AIR AND RATE OF ACID FORMATION REACTION



RELATIVE RATE ACID PRODUCTION

$$\text{Reaction} = \frac{100\,(O_2\ \text{Conc})^3}{8000}$$

reduction in reaction rate and that a reduction of 50%, corresponding to about 10% oxygen left in the mine air, produces a reduction of roughly 87% in the reaction rate.

Figure Ac-5 presents a curve showing this hypothetical rate of acid formation with reduction in atmospheric oxygen.

Although this question was studied briefly by the Morgantown laboratory unit, there are no final experimental data to support the hypothesis advanced.

Remedial Measures

Acid mine drainage has been an acute problem for several decades and its history involves extensive study of remedial methods and court action. Early efforts considered neutralization and recovery of by-products while more recent efforts have been toward prevention of formation of the acid and equalization of stream flow. Corrective efforts can be divided into five classes:

1. Mine Sealing - Abandoned Mines
2. Mine Sealing - Active Mines
3. Flow Control
4. Neutralization
5. Miscellaneous Methods.

Mine Sealing - Abandoned Mines - A most promising line of attack of the acid mine drainage problem is that of preventing acid formation by sealing abandoned mines, thus eliminating most of the oxygen which is essential for acid formation and, in some measure, reducing water entering the mine.

In 1925 the U. S. Bureau of Mines began a series of field and laboratory studies on the subject of acid mine drainage and were later able to demonstrate the feasibility of preventing acid formation by sealing. All subsequent work has been based on the foundation of these early studies and demonstration. Large scale sealing of abandoned coal mines in the last seven years has confirmed the earlier work. The reduction of acid formation is based upon the principle that the exclusion of air (oxygen) from the mines will prevent the oxidation of pyrite, marcasite, and other sources of sulphur in the presence of water. Diversion of surface water from entry into mines through cracks and caves is also done in order to minimize the amount of water in the mine and prepare these entries for surface sealing. Water in the mine is allowed to drain through trapped openings.

Air sealing, to be effective, must include a maximum of surface sealing. Thereafter, with proper maintenance, a reasonable expectation is an average reduction of about 65 percent in flow, 40 percent in phenolphthalein acidity, 10 percent in methyl red acidity and possibly 80 percent in the total quantity of acid discharged as measured in tons. There may be little immediate improvement in quality and the free acid concentration may be increased above normal for several years. Figure Ac-3 shows expectancy curves for mine sealing performance from the record of 100 sealed mines in West Virginia.

Sealing of abandoned coal mines was begun on a large scale in 1933. The program was instituted and presented through the combined efforts of the Ohio River Board of Engineers, the U. S. Public Health Service, various State Health Departments and Federal relief agencies. Work was carried on intermittently until 1935 when the program was placed on a regional basis under the Works Progress Administration and the U. S. Public Health Service with the State Health Departments cooperating.

The program has been carried on until the present time (1940) in West Virginia, Maryland, Ohio, Alabama, Tennessee and Indiana. Although far from completed, work was stopped in Pennsylvania and Kentucky in 1938. Work in Illinois has been largely completed. No work has been done in Virginia.

The mine sealing program in the past has been a relief measure and, as a result, activities have tended to concentrate in areas of greatest relief need rather than in areas of greatest acid control need. Considered primarily as a relief measure, this tendency has been proper. In general, a cost limitation of $10.00 per ton per year has been in effect. Such economical projects should be attacked first. Indications are that extension of this cost limitation to a somewhat higher figure is justified particularly in critical areas. The present mine sealing authorization is for abandoned mines and does not cover areas that are connected with an active ventilation system. In a truly comprehensive program such areas should, in many cases, be brought within the range of control.

Any stream improvement program, be it an organic pollution remedial measure or one for acid control, requires a continuing effort in the form of sewage or industrial waste treatment plant operation or mine seal inspection and maintenance. This feature is of particular importance in connection with mine sealing. In some states, provisions for maintenance are inadequate and the seals are reported to be breaking down. A mine sealing program should include provision for inspection and maintenance or the program will be of only passing benefit.

Inspection is estimated at 2 percent. Maintenance may be 15 percent or higher for a few years reducing to a low figure as the seal becomes stabilized. A range of from 7 to 10 percent will probably represent average conditions. If interest ($3\frac{1}{2}\%$) and amortization (0.7 percent based on a 50 year life and $3\frac{1}{2}$ percent interest) are added, annual charges will total about 15 percent.

Mine Sealing - Active Mines - In carrying out possible air sealing activities in connection with active mines, it is necessary to enter the mine where active mining operations are still in progress. This is properly the jurisdiction of the mining departments and any proposed activity is a matter for State mining department supervision. However, acid from operating mines presents a pollution problem and is therefore also within the jurisdiction of pollution control agencies. This problem, therefore, requires close coordination of the activities of the two administrative agencies.

The acid produced in active mines represents a large proportion of the total mine acid production and to date no extensive attempts have been made to offset this load. However, based upon the demonstrated success of sealing abandoned mines, the possibility of minimizing to a great extent the acid production in active mines by surface sealing for diversion of surface water and air sealing of worked-out sections in the mine is worthy of careful consideration.

With orderly panel developments of mines and the use of barrier pillars to minimize the number of openings to various portions of the mine, air sealing of worked-out sections can be accomplished at low expense. Both surface and air sealing would reduce acid production and the results of such sealing would be of great benefit not only in reducing stream pollution but also in lowering mine operating costs. Direct benefits to mine operators that would accrue through sealing may be summarized as follows:

(1) Decreased pumpage - This would result mainly from surface sealing of cracks and caves and consequent diversion of surface water from the mine. Pumping costs are a substantial operating expense item at most large mines and any reduction in water entering the mine would result in a significant saving.

(2) Lower costs for ventilation - An unsealed worked-out section requires ventilation to eliminate the hazards of gas (methane) which is encountered in many mines. This results in considerable ventilation expense chargeable to areas no longer yielding any return. If these sections were air sealed by the conventional method involving the use of a water trap, ventilation would no longer be required. Where excessive amountsof gas are encountered it would be necessary as a safety measure to provide for pressure relief by suitable means.

There may also be a benefit due to a lesser acid quality of the water but, as pointed out, this is not certain at least for a period of several years.

The net reduction in quantity of water, ventilation area and possibly quality of water on a conservative basis is ample to make sealing of worked-out sections of active mines attractive. Although detailed studies are not available, it is quite possible that savings would be sufficient to amortize the required investment. Experience with abandoned mines clearly indicates that improvement is possible in the discharge from worked-out sections of active mines. A suitable actual demonstration is needed to facilitate adoption of the proposal in general practice.

The sealing of worked out sections is permissible under the mining laws of several states provided that such seals do not cause impoundment of large quantities of water under any considerable head. Such a condition would obviously be hazardous to nearby active workings. Fortunately, sealing causes no dangerous impoundment since the water can pass readily through the air seal. Sealing of worked-out areas has been practiced to a limited extent but with considerable success in one state.

Mine Sealing - Economic Considerations - The cost of sealing a mine is roughly proportional to the number of acres of the coal measures which have been mined out. However, certain mines, for reasons not thoroughly understood, produce far more acid per acre mined out than others even though all may be relatively close to each other and may have worked the same coal seams. Thus the cost of sealing a low acid producing mine may well be as high or higher than the cost of sealing a comparable mine producing much more acid. This suggests that a maximum sealing cost, based on the cost per unit weight of acid sealed, be established. Under the present program this has been set at approximately ten dollars per ton, per year. As might be expected, statewide averages for sealing work to date, as shown in Table Ac-2, have been less than this figure. However, use of such a limiting figure is restricted to large areas; and when the problem of economical use of mine sealing funds is viewed on the basis of small areal units, such as counties or small watersheds, the difficulty of applying any rigid economic standard becomes apparent. In such cases the answer to the question of how much should be spent per ton of acid sealed should be based on an estimate of how much acid removal is worth from the standpoint of various water uses. For example, on a small stream receiving the

drainage from only a few abandoned mines and no other pollution the value of acid removal or reduction might well be many times as great as the corresponding value on a similar stream subject to heavy pollution from many different sources. In the latter case the economic limit might well be far less than any statewide or regional average standard while in the former it conceivably could be much greater.

Flow Control - In many streams, the natural alkalinity of the water is ample during normal times to neutralize the acid mine drainage load placed upon it and leave a satisfactory residual alkalinity. However, at certain times, the flow of the stream may not be sufficient to absorb the load and normal aquatic life requiring a continuous satisfactory habitat may be damaged or destroyed. It follows that if alkaline water from storage can be added at such times the damage caused by the acid mine drainage load will be greatly reduced.*

The construction of a reservoir for the sole purpose of supplying flows to neutralize acid mine drainage would be unduly expensive. However, there has been a trend in the past decade toward the construction of multipurpose reservoirs or, more commonly, toward the multipurpose use of what are primarily flood control reservoirs. Effectiveness for the specific purpose of acid control is somewhat reduced under these conditions but the neutralization of acid mine drainage need justify only a part rather than the whole cost of a reservoir. Flow control as a means of correcting acid mine drainage conditions, particularly in leveling off fluctuations, appears worthy of serious consideration.

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* In waters containing mine drainage, there are theoretical considerations that indicate that it is not strictly correct to deduct alkalinity values from acidity values. The low alkalinity values obtained in acid mine river samples may be the result, in many cases, of partial and incomplete hydrolysis of the iron salts contained therein. When such samples are added to samples which are already acid a dilution of the unhydrolyzed iron salts would occur which would hasten the hydrolysis and establish a newequilibrium. Consequently, river samples which are slightly alkaline and contain iron salts will not always be capable of stoichiometrically neutralizing samples which are already acid. Because of a lack of sufficient data it is impossible to calculate the exact result of mixing samples of this kind in terms of alkalinity or acidity. However, the present procedure is considered satisfactory for the practical purpose of presenting the results as it is the simplest for purposes of presentation and not believed to be greatly in error.

Mine Sealing vs. Flow Control - During the past few years there has been considerable mine sealing activity in West Virginia on the Monongahela watershed. At the same time the Tygart Dam has been constructed and operated to maintain increased low flows. Both of these activities have had a beneficial effect on the stream and any complete program of acid control will probably require the use of both control methods.

The essential difference in the operation of the two acid control methods is that mine sealing reduces the acid load throughout the year while flow control causes no acid reduction but simply stores water during periods when excess alkalinity is available and saves it for discharge during subsequent periods when acid conditions are serious. Reservoir operation may also smooth out objectionable day to day acid surges. Acid reduction by sealing may vary considerably from month to month and, as a rule, is more effective during the low-flow months.

As multipurpose use of a flood control reservoir involves no appreciable storage from one year to the next, it is safe to assume that such a reservoir will not change the total tons of acid discharge during the year. In other words, the reservoir stores the alkaline flow for later discharge during an acid period in the same year. This means that annual average tons of acid discharge can be plotted to show trends with the effect of storage dams eliminated.

In order to illustrate the effect of the two control methods, in simplified form, Figures Ac-6, Ac-7 and Ac-8 have been prepared. These figures are based on a stream whose weighted average daily quality is neutral and which approaches the quality of the Monongahela River about the year 1920, as measured by the methyl orange indicator. Figures Ac-6 and Ac-7 show identical effects of the two methods of control as far as reductions of peak acidity and acid days are concerned. Figure Ac-8 shows the effects of the two methods of control added together to eliminate acid conditions in the stream.

The principal point of difference illustrated by Figures Ac-6 and Ac-7 is that mine sealing reduced the weighted annual average acidity while reservoir operation equalizes the discharge of alkalinity. The principal point illustrated by Figure Ac-8 is that the effects of the two methods of control actually can be added together to correct situations where either method alone might not prove adequate.

The functions of the reservoir, as stated, are to equalize the flow of natural alkalinity available for acid neutralization and to eliminate day to day acid surges. However,

as a reservoir does not affect the weighted average quality of the discharge, no amount of reservoir operation can make an alkaline stream of one whose average quality is acid.

Mine sealing on the other hand can be used to attack practically any situation with some hope of restoring a stream to alkaline conditions. While mine sealing cannot be applied to acid from active workings, as can reservoir operation, it should be pointed out that probably not over 10 percent of the total acid load comes from working areas. A stream restored to average alkalinity by sealing operations may still suffer from acid surges for which a reservoir is needed. In general, the two methods of acid control supplement one another.

Flood Control Reservoirs - The discussion of flow control thus far has been based on the assumption that the reservoir has been operated solely for the control of acid. Under such circumstances, alkaline water is stored only when there is an excess or balance of alkalinity in the stream and is discharged whenever the stream becomes acid. When the primary purpose of a storage reservoir is flood control, such ideal operation is not always possible. Using the Tygart Reservoir as an example, the plan of operation is to hold the reservoir at a low level (El. 1010) for flood protection until about April 10 and to fill the reservoir to elevation 1094 from April 10 to about June 15, leaving a lesser capacity available for flood control during and after this period. From about July 1st to December, the reservoir is used to increase low flows leaving the reservoir at a low level at the end of the year for flood control. Figure Ac-9 shows Tygart Dam operation in 1939 together with the pool elevation guide line.

Tygart Dam has, without doubt, had a beneficial effect on the water supply of Morgantown, West Virginia, 50 miles below on the Monongahela River. However, the main storage takes place in April, May and June rather than during periods of excess alkalinity. Figure Ac-10 shows, as near as can readily be computed, the effect of Tygart Dam on the acidity of this supply by months from July, 1938, through 1940. This shows that during the six main storage months in this record, alkalinity was available within the storage requirements during three months but was not available during the other three months. Therefore, during these latter three months the acidity at Morgantown was actually increased by Tygart Dam operation. Against this, there were six months in the 30-month period when the acidity was decreased and during two of these, the acid was neutralized.

Reproduced from best available copy.

It is of interest that Tygart Valley waters were substantially reduced in acidity by mine sealing before the dam was put in operation, thus illustrating again how the two control methods supplement one another.

Neutralization - For many years consideration was given to abatement of the mine acid pollution problem by chemicals such as lime or limestone for neutralization. However, such treatment methods proved to be impractical due to the expense of operation and initial treatment plant construction. Estimates indicate that to treat all acid mine drainage in Pennsylvania, Maryland, Ohio and about half of West Virginia would require an initial plant investment of approximately $242,000,000, with annual operating costs of about $132,000,000. This annual operating cost compares favorably with the annual value of all the bituminous coal produced in Pennsylvania in recent years and amounts to an annual charge of about 50 to 60 cents per ton of coal produced yearly in the states named. For the entire United States the cost has been estimated at about $330,000,000 for plant construction with operating costs at $180,000,000 per year. No readily marketable by-products result from neutralization processes to help defray expense. In addition, the difficulty of disposing of the enormous amounts of iron and aluminum hydroxide sludge produced by neutralization is considered to be significant.

Miscellaneous Methods - A number of miscellaneous acid control methods have been used or suggested. One of these is an established policy of refraining from discharging acid waters to streams previously uncontaminated. In some cases this is highly desirable and the policy might be advantageously expanded in special cases.

Flooding or impounding is the natural result of discontinued pumping with abandonment of shaft mines. In other cases flooding appears dangerous and impractical, as well as being a poor substitute for mine sealing.

Regulation of mine openings and concentration of discharge has little over-all effect. A certain acreage of coal will be mined each year and the acid production will not be changed whether the coal is mined in new territory or old. Concentration of acid pollution brings about critical conditions. Dispersion may keep the acid within controllable limits.

Fig. Ac-6

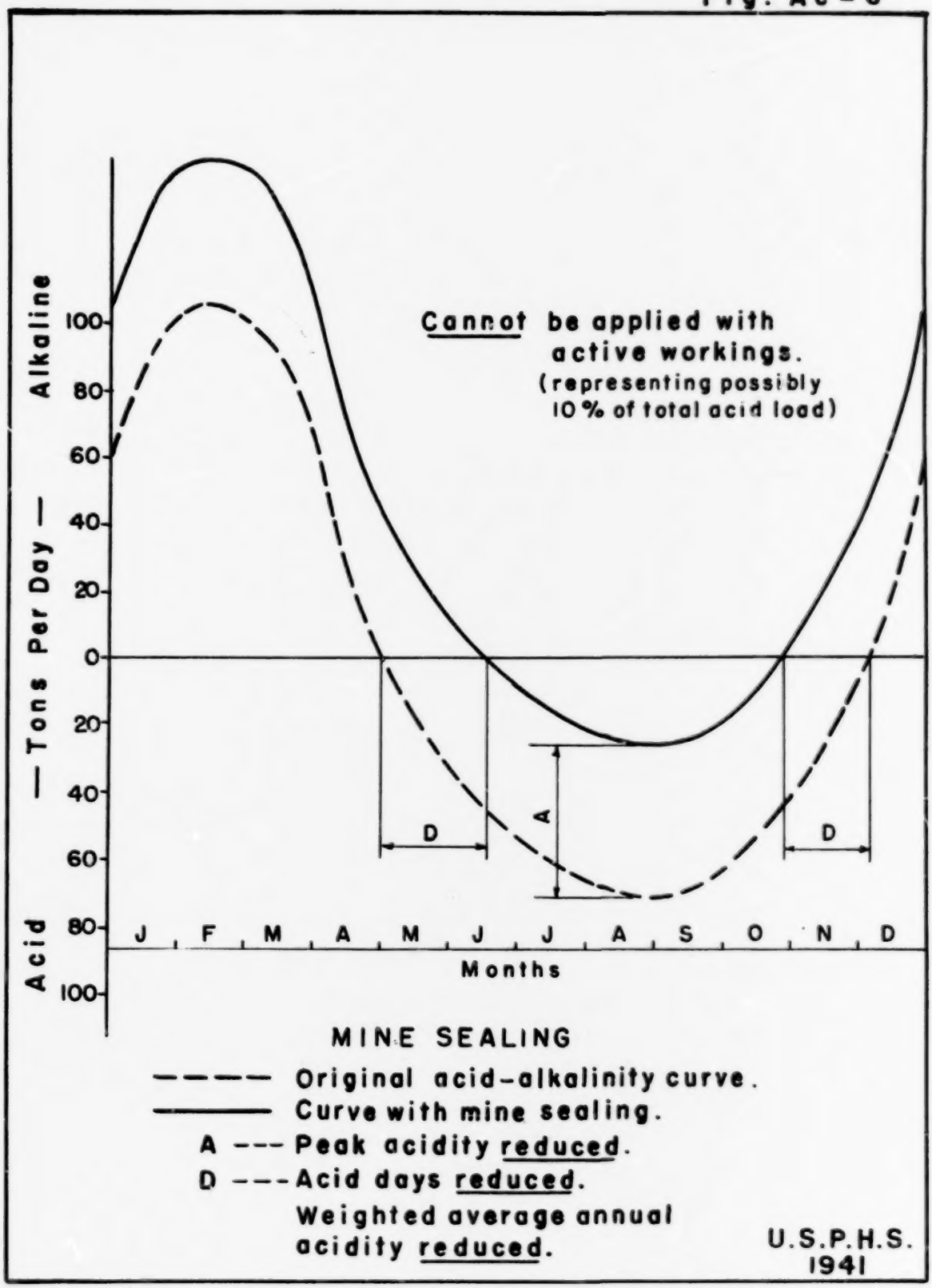

Cannot be applied with active workings. (representing possibly 10% of total acid load)
Acid — Tons Per Day — Alkaline
100
80
60
40
20
0
20
40
60
80
100
D
A
D
J F M A M J J A S O N D
Months
MINE SEALING
Original acid-alkalinity curve.
Curve with mine sealing.
A --- Peak acidity reduced.
D --- Acid days reduced.
Weighted average annual acidity reduced.
U.S.P.H.S. 1941

Fig. Ac - 7

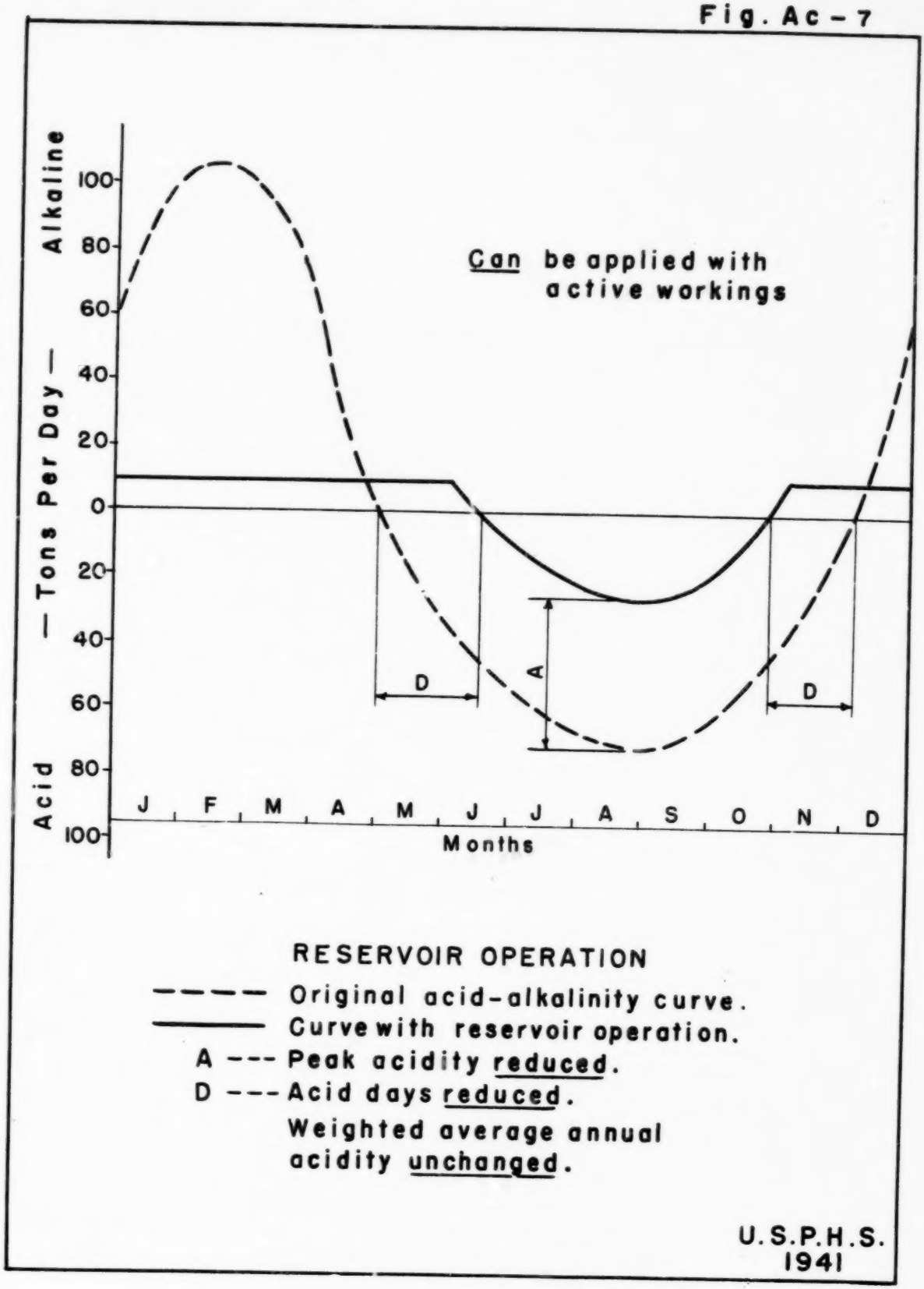
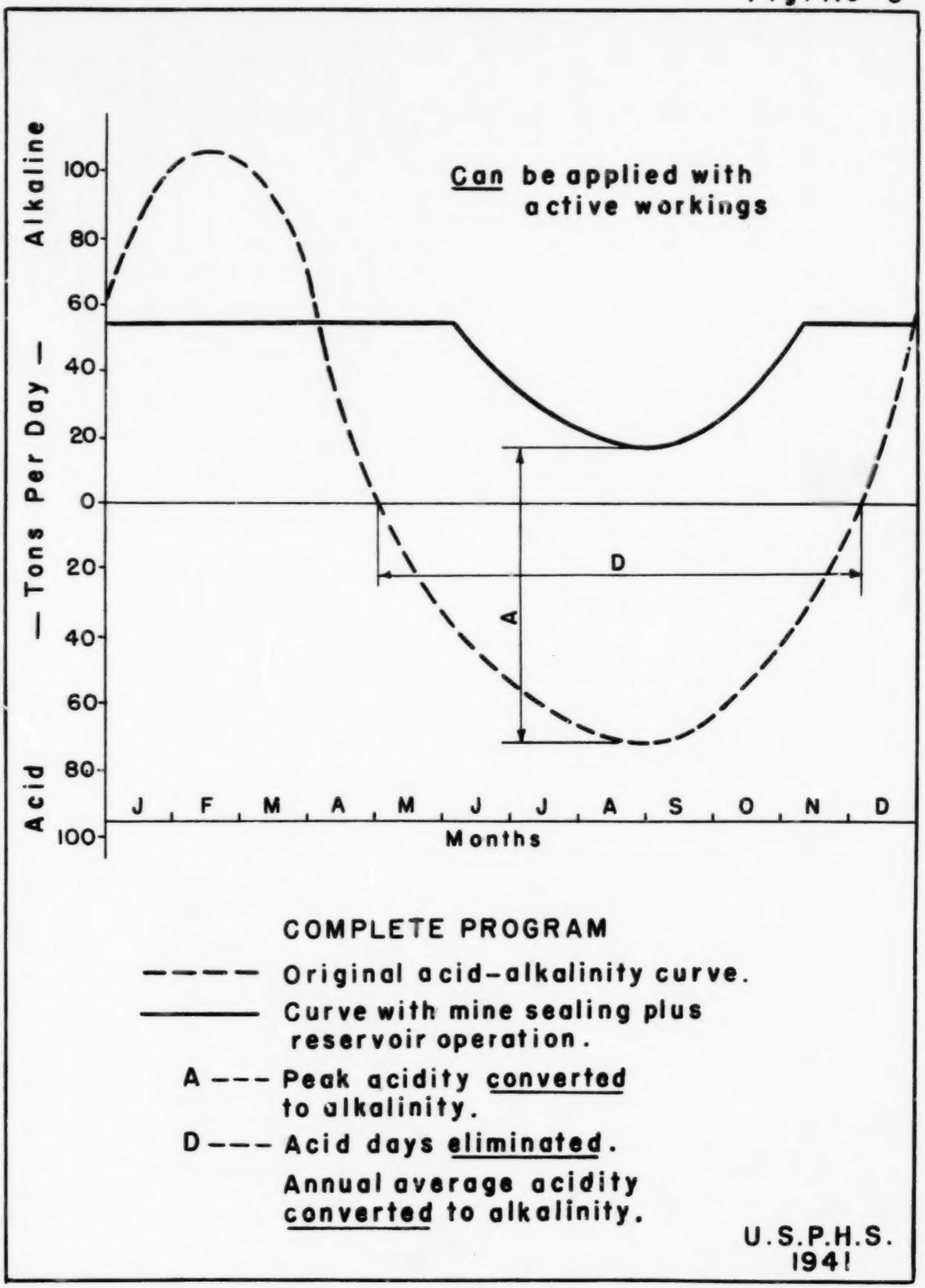
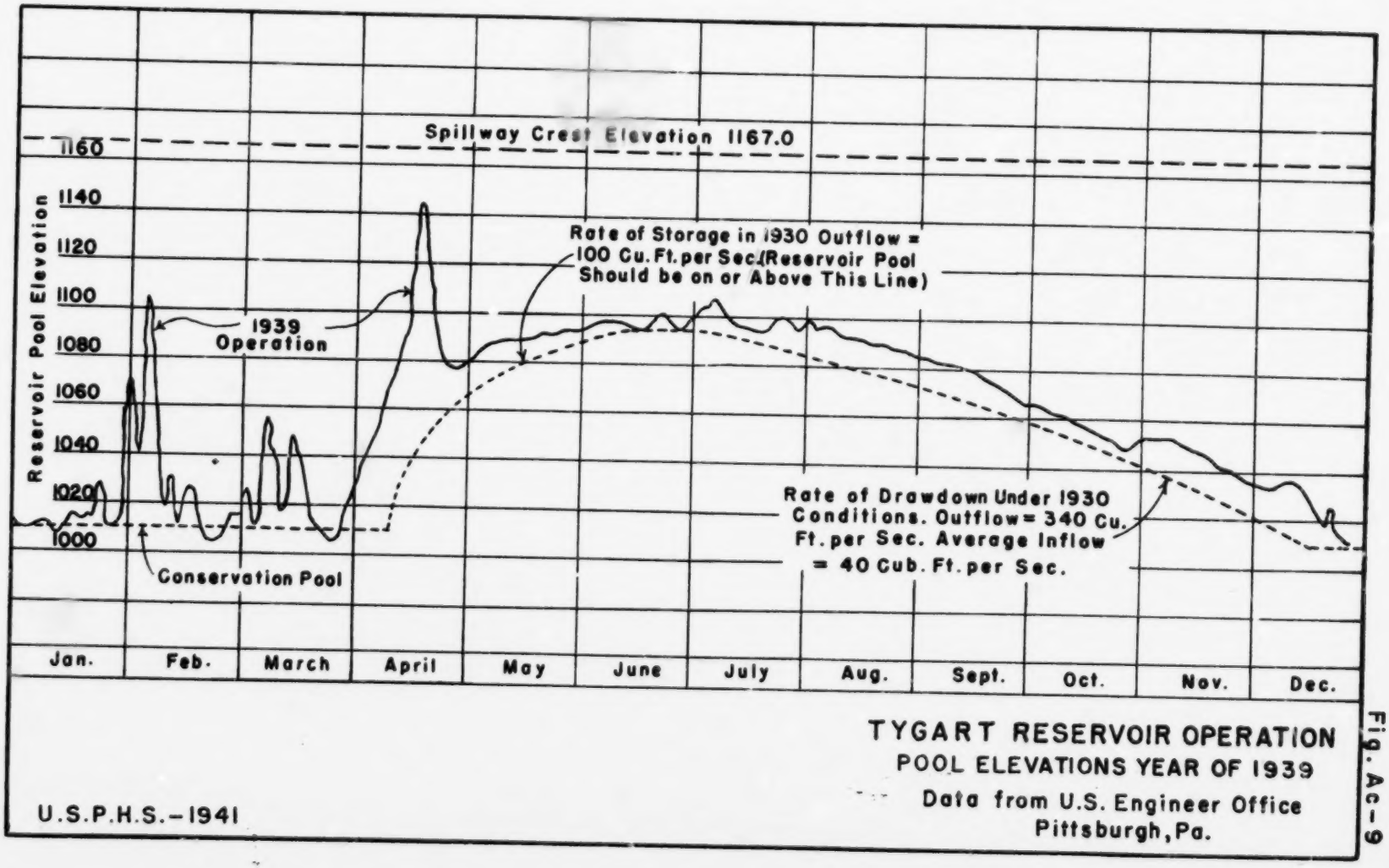

Alkaline
— Tons Per Day —
Acid
100
80
60
40
20
0
20
40
60
80
100
Can be applied with active workings
D
A
D
J F M A M J J A S O N D
Months
RESERVOIR OPERATION
Original acid-alkalinity curve.
Curve with reservoir operation.
A --- Peak acidity reduced.
D --- Acid days reduced.
Weighted average annual acidity unchanged.
U.S.P.H.S.
1941

Fig. Ac-8


Can be applied with active workings
Alkaline
Acid
— Tons Per Day —
100
80
60
40
20
0
20
40
60
80
100
D
A
J F M A M J J A S O N D
Months
COMPLETE PROGRAM
Original acid-alkalinity curve.
Curve with mine sealing plus reservoir operation.
A --- Peak acidity converted to alkalinity.
D --- Acid days eliminated.
Annual average acidity converted to alkalinity.
U.S.P.H.S.
1941



TYGART RESERVOIR OPERATION
POOL ELEVATIONS YEAR OF 1939
Data from U.S. Engineer Office
Pittsburgh, Pa.

U.S.P.H.S.-1941

Fig. Ac-9

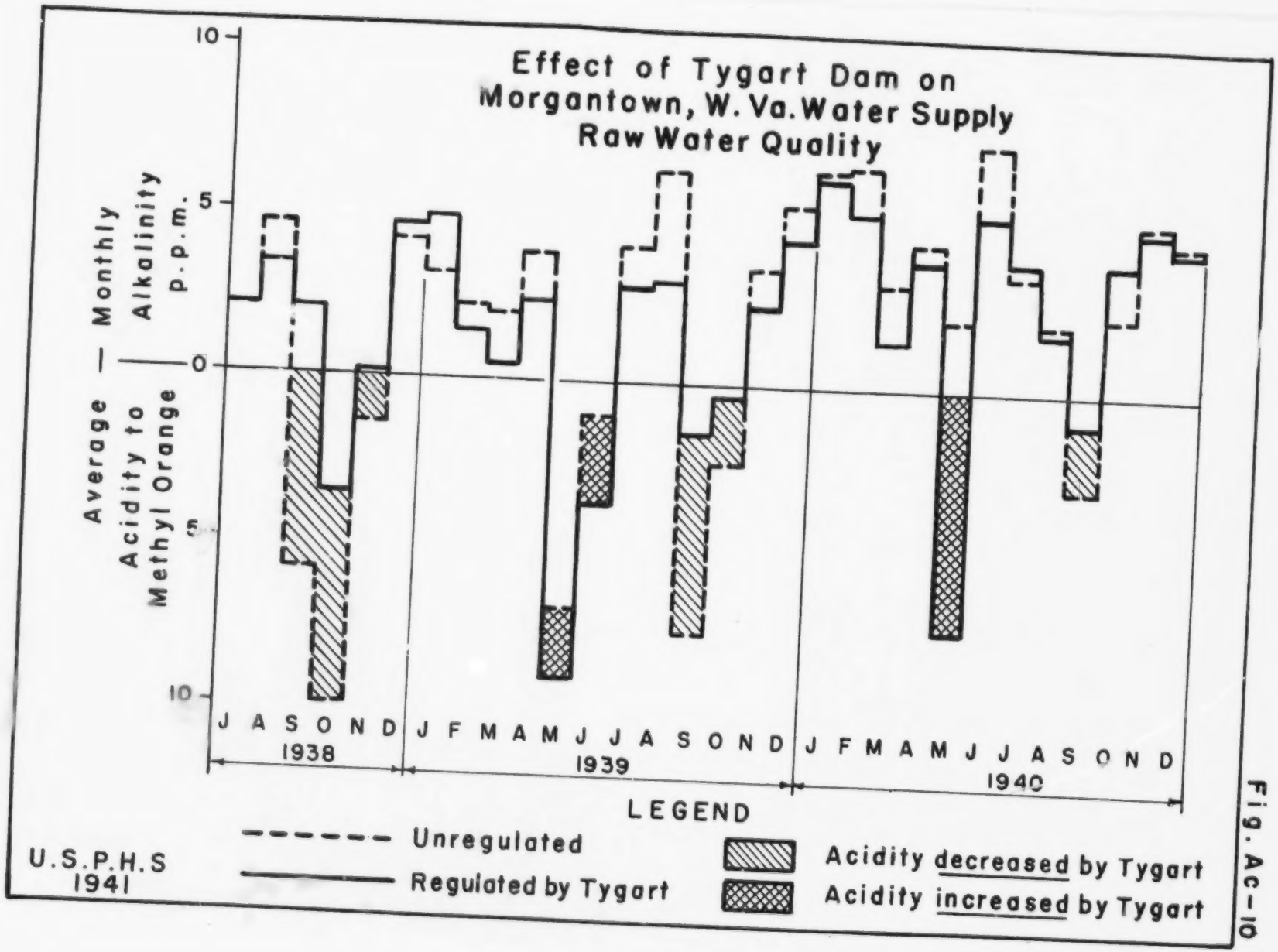

Effect of Tygart Dam on
Morgantown, W. Va. Water Supply
Raw Water Quality
Average — Monthly
Acidity to Methyl Orange — Alkalinity
p.p.m.
10
5
0
5
10
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1938
1939
1940
LEGEND
Unregulated
Regulated by Tygart
Acidity decreased by Tygart
Acidity increased by Tygart
U.S.P.H.S
1941

Fig. Ac-10

Statutes and Court Decisions

Legal efforts to control acid mine drainage through enactment of State laws or through court action have made little progress. Of the two legal approaches, court action has been the more successful. Ohio, Pennsylvania and West Virginia have laws specifically exempting mine drainage from control while in one instance, the Indian Creek case, court action was successful in obtaining relief.

Statutes - The mining laws of the states of the Ohio River Basin are administered by the State mining departments whose duties are to execute and enforce the State mine inspection laws, enacted for the safety of persons employed within or at the mines and the protection of mine property and other property used in connection therewith. It is the duty of the Chief Mine Inspector to report improvement of methods, conditions, development, and progress in mining with reference to health, safety, economy and conservation.

The States of Ohio, Pennsylvania and West Virginia have Sanitary Regulations pertaining to the disposal of sewage and industrial wastes but in these States acid mine drainage is exempt until treatment and/or disposal methods are developed. The mining laws of West Virginia provide that mine drainage waters be free from pollution by human and animal excrement or substance deleterious to health.

The mining laws of Kentucky, Tennessee, Virginia and West Virginia state that it is the duty of the mine foreman to remove water from working places within the mines. Alabama, Georgia, Illinois, Kentucky, Pennsylvania, and North Carolina provide regulations in their mining laws for eminent domain, that whenever any mine or ming place shall be so situated that it cannot be conveniently worked without a ditch to drain or convey water thereto, the owner or operator may construct such ditch when he complies with the law of eminent domain. The Kentucky law states, "the water so drained or pumped from such mines shall be drained as directly as practicable to adjacent streams or watercourse by means of ditches, flumes, pipes, sewers or other adequate provisions."

The Pennsylvania mining laws provide for the sealing of abandoned mines but do not prescribe the method. The laws of Indiana, Ohio and Virginia permit the sealing of worked-out sections of active mines while West Virginia does not prohibit this sealing. Ohio and other states provide for closing and/or fencing abandoned mine openings to prevent entrance thereto.

Table Ac-7 Acid Mine Drainage - Summary of State Mining Laws Pertaining to Acid Mine Drainage.

State	Mining Regulations providing for		
	Sealing of Abandoned Mines	Sealing of Abandoned Workings of Active Mines	Exempting Acid Mine Drainage from Regulation
Alabama	-	-	-
Georgia	-	-	-
Illinois	-	-	-
Indiana	-	Yes	-
Kentucky	-	-	-
Maryland	-	-	-
No.Carolina	-	-	-
Ohio	-	Yes	Yes
Pennsylvania	Yes	-	Yes
Tennessee	-	-	-
Virginia	-	Yes	-
W. Virginia	-	Not prohibited	Yes

Regulations of Alabama, Maryland, Pennsylvania and Virginia provide for the reopening of old and abandoned mines and for the drainage of water therein. All states have safety regulations governing the approach to abandoned mines or worked-out sections which may have dangerous accumulated water or gas.

Table Ac-7 summarizes the State laws on certain features of the acid mine drainage problem. In general, it appears that there are as many laws hindering the control of acid mine drainage as there are assisting this control.

Court Decisions - The two court decisions relating to acid mine drainage, the Indian Creek case and the Sanderson case, are basic in character and rather widely known. In the Indian Creek case, the Court found in favor of a water company as the water was considered more important to the Commonwealth than the coal. In the Sanderson case, the reverse was true, as the Court found in favor of the coal mines as the coal was considered more important. The following is, in part, from a published summary of a discussion of these two cases.

Indian Creek Case - The Mountain Water Supply Company was organized in 1905 and appropriated the water of Indian Creek to supply the Pennsylvania Railroad System in southwestern Pennsylvania, as far west as Pittsburgh. A large storage dam was built about 4 miles from the mouth of Indian Creek. The drainage area above this point is 110 square miles, of which 55 square miles were underlaid with the lower coal productive measures. In addition to supplying the Railroad Company, the Water Company furnished water to several municipalities in western Pennsylvania, supplying about 75,000 people. Active coal development began on a large scale, and it was apparent that this important water supply eventually would be damaged or destroyed if mining continued. The water company appealed to the Courts for an injunction to restrain the coal companies from discharging acid drainage into Indian Creek above the dam.

The Fayette County Court decided there was no public use of the water and that preventing the mining companies from discharging water into Indian Creek would deprive them of the use of their property. The court refused to grant an injunction restraining the mining companies from discharging mine water into this stream. The Pennsylvania Supreme Court reversed the lower court declaring that it was not a question of property rights, but that it was a nuisance to pollute the stream and that the mining companies should not, after a certain period, discharge the mine water into Indian Creek or

its tributaries above the dam of the water company. This opinion which was concurred in by the U. S. Supreme Court, states:

> "It is controlled by one fact and a single equitable principle; the fact that the stream has been polluted, and the principle that this creates an enjoinable nuisance if the public uses the water."

Sanderson Case - In 1886 Sanderson bought property in the City of Scranton through which flowed Meadow Brook, a pure, unpolluted stream. He built a dam and developed a water supply for his own use. About the same time Pennsylvania Coal Company opened a coal mine which soon produced acid mine drainage destroying the use of the brook water. Sanderson brought suit for damages resulting from loss of the stream. The case was twice tried in courts of Lackawanna County, Pennsylvania, and was twice before the Supreme Court of Pennsylvania. The Supreme Court decision affirmed the lower court's award of damages to Sanderson; Justice Paxon filed a strong dissenting opinion, which was sustained in the second Supreme Court decision.

The Court took the position that if Sanderson could collect damages every riparian owner thus affected could do likewise and if they could collect damages they could also enjoin the pollution of streams by mine drainage which would practically stop all mining operations except by consent of the lower riparian owners; that trifling inconvenience to particular persons must sometimes give way to the necessities of a great community, especially where the leading industrial interest of the state is involved. The court further stated in its opinion that the coal company was making the natural and ordinary use of its property, and that Sanderson with others was then securing an abundant supply of pure water from other sources, but that it would not say that a case "may not arise in which a stream, from such pollution, may not become a nuisance, and that the public interests as involved in the general health and well being of the community may not require the abatement of that nuisance."

The difference between the Sanderson and the Indian Creek decisions is that Sanderson, an individual who had access to another good supply of water, was not permitted to stand in the way of Pennsylvania's greatest industry whereas in the Indian Creek case the public, also represented by the Commonwealth, was fighting to preserve one of the last available pure water supplies in the state, and the decision merely carried out one of the principles enunciated in the Sanderson decision.

Presentation of Field Data

Mine Acid Loads

In collecting information on mine acid loads in the Ohio River Basin valuable assistance was furnished by the personnel of the Office of Mine Sealing. In certain cases, records were summarized from state files but in all cases the information was checked by Mine Sealing personnel familiar with the work in the various states. This personnel is of the opinion that certain portions of the load estimates are based on less than satisfactory complete data. However, it is agreed that the estimates are the best available and that improved estimates would require extensive sampling and gaging studies, neither possible nor justified, for the purpose of the Ohio River Pollution Survey.

Magnitude - Table Ac-1 indicates the magnitude of the acid mine drainage problem by states and major tributary basins in terms of tons of acid produced annually by active, marginal and abandoned mines, the estimated present status of the remedial measures of mine sealing and the estimated portion of the total acid load which may be removed economically by sealing methods under restrictions of 1940.

Figure Ac-2 shows, in graphical form, the magnitude of the original mine acid loads and the reduction by present and possible future economical mine sealing under 1940 restrictions in each state. As there are two distinct coal fields in Kentucky, one in the east and one in the west, two symbols have been used in this state, one for each coal field.

Intensity - The intensity of the acid load is given on Table Ac-1 in terms of tons per square mile per year. These figures show strikingly that the problem is acute in the areas drained by the Monongahela, Youghiogheny and Kiskiminetas Rivers and in the states of Pennsylvania and West Virginia. The loads given are prior to sealing and more recent residual loads are, in certain cases, much less.

Pickle Acid Comparison - Table Ac-8 presents a summary of mine acid loads (to phenolphthalein) in 1000 pounds per day and compares these figures with the free acid loads from waste pickle liquor. The pickle liquor free acid load shown as 3.4 percent of the present mine acid load does not include the iron salts which are probably hydrolized to some extent in solution to form sulphuric acid. This latter acid, which must

Table Ac-8 Acid Mine Drainage - Summary by Tributary Drainage Basins, of Original Mine Acid Loads and Mine Acid Loads after Present Sealing and Complete Sealing Program under 1940 Restrictions Together with Comparison with Waste Pickle Liquor Free Acid Loads.

Tributary Drainage Basin	Mine Acid Loads as $CaCO_3$			Free Acid Load from Pickle Liquor as $CaCO_3$ (1)	
	Original	After Mine Sealing			
		Present (A)	Complete Program		
	1,000 Pounds per Day				Percent of (A)
Alle. R. except Kiski.	456	355	177	17	4.8
Kiskiminetas River	1,764	1,703	975	10	.6
Allegheny River Total	2,220	2,058	1,152	27	1.3
Monon. except Yough.	3,841	2,461	1,827	57	2.3
Youghiogheny River	1,204	1,079	624	-	0
Monongahela River Total	5,045	3,540	2,451	57	1.6
Beaver River	95	83	47	64	77.
Little Kanawha River	4	2	2	0	0
Kanawha River	180	105	93	0	0
Guyandot River	111	60	52	0	0
Big Sandy River	334	253	153	0	0
Muskingum & Hocking Rivers	1,182	681	577	11	1.6
Scioto River	132	98	59	0	0
Little Miami River	0	0	0	0	0
Licking River	Slight	-	-	0	0
Miami River	0	0	0	55	-
Kentucky River	230	167	115	0	0
Salt River	0	0	0	0	0
Green River	419	336	210	0	0
Saline River	Slight	-	-	0	0
Tradewater River	43	39	21	0	0
Cumberland River	1,451	1,073	563	0	0
Tennessee River	209	120	61	0	0
Wabash River	600	343	176	2	0.6
Main Ohio River - Pa.	271	221	139	32	14.5
Ohio	622	486	266	31	6.4
W.Va.	147	97	87	48	49.5
Ky.	94	73	46	9	12.3
Ind.	72	38	36	-	0
Ill.	14	13	7	-	0
Main Ohio River Total	1,220	928	581	120	13.0
Unclassified - Virginia	103	103	42	-	-
Total Ohio River Basin	13,578	9,989	6,355	336	3.4
Percent Waste Pickle Liquor Acid-Mine Drainage Acid	2.4	3.4	5.3	-	-

(1) Does not include iron salts.

be included in any neutralizing plant, may vary from a minor item to 8 or 10 times the free acid load depending on the hydrolysis equilibrium. Acid pickle liquor wastes are important in local areas particularly in the vicinity of outfalls but they are less of a general problem than acid mine drainage.

Mine Sealing Costs

Table Ac-2 presents statewide and Ohio River Basin figures for the cost of mine sealing to date and cost estimated to complete a program of mine sealing under 1940 restrictions. The complete program mentioned here and in other discussions contemplates sealing all acid discharges that can be sealed for a cost not exceeding approximately ten dollars per ton per year. As pointed out in later discussions, this cost limitation can be extended and such extension appears justified.

Mine Acid Effects

Mine drainage, containing sulphuric acid and the acid salts (sulfates) of iron and aluminum, which reaches the surface streams in the bituminous coal mining areas in Pennsylvania, West Virginia, Maryland, Ohio, Indiana, Kentucky, Illinois and Virginia, is one of the most damaging industrial wastes in the Ohio River Basin. Pollution from this source is greatest in Pennsylvania and West Virginia, the two largest bituminous coal producing states. Unlike most damages caused by sewage and organic industrial wastes, most damages from acid mine drainage are real and tangible and can be estimated with a reasonable degree of accuracy.

The immediate effect of acid mine water on small and large streams is to change the chemical character of the water. More specifically, acid mine drainage will:

(1) Destroy or materially reduce the natural alkalinity resulting in conversion of carbonate to noncarbonate hardness.

(2) Lower the pH.

(3) Increase the total hardness.

(4) Add objectionable amounts of iron, manganese, aluminum and sulphate to the water.

These changes result in damages to the stream, both tangible and intangible. The tangible damages which have been evaluated are briefly as follows:

(1) The water is rendered expensive and difficult to treat for municipal and industrial use.

(2) The water is rendered highly corrosive to ordinary steel or iron structures and equipment such as culverts, bridges, locks, boat hulls, steel barges, pumps and condensers. Concrete structures are also damaged.

The intangible damages, which are nonetheless real and important, are briefly as follows:

(1) The streams are often rendered unsatisfactory for normal recreational use; i.e. fishing, boating, swimming.

(2) The biological processes and characteristics of the streams are substantially altered. Normal biological activity is retarded. In other words, the stream is no longer the habitat for desirable aquatic life.

(3) Chemical precipitation action of iron and aluminum salts, combined with the low velocity in the navigable channels, results in the heavy deposition of sewage solids particularly below Pittsburgh, and the ensuing flush-out by high water causes a wide fluctuation in quality, as reported by water plant operators, to pass down the Ohio River to the great detriment of public water supplies and hazard to the public health.

Acid mine drainage has served as a deterrent to the abatement of other types of pollution, particularly of an organic nature. There is no great incentive nor, in fact, justification for sewage treatment or the correction of organic industrial pollution if the result will be a stream that remains unsuitable for any use other than the disposal of mine waters. While other sections of the country have made substantial progress in the restoration of streams, the mining areas are notable for the few sewage treatment plants to be found.

The germicidal, inhibiting and other effects of the acid may prevent odor nuisance, a point which has been the subject of considerable discussion. However, the visual nuisance may

remain and from a public health standpoint or in the protection of public water supplies, acid mine drainage is not a dependable safeguard. During a freshet the rapid increase in flow may bring sufficient alkalinity to neutralize the acidity and eliminate the germicidal effect. This would happen at the same time that accumulated sludge deposits are being flushed out and the greatest need for a germicidal effect occurs. A water plant depending on acid mine drainage germicidal action would be operating under a greatly reduced factor of safety.

Evaluation of Damages

Damages caused by acid mine drainage differ from most damages caused by organic pollution in that many of them have a definite quality and are capable of accurate determination in dollars. While damages due to impaired recreation, the creation of a nuisance and hazard to the public health are equally real and important, a monetary estimate of the extent of such damages must be based on assumptions of the person making the estimate. No assumptions are necessary to determine the cost of chemicals for neutralizing a raw water or removing noncarbonate hardness. The cost of removing a barge or towboat from service for extra painting and the cost of that painting can be determined with accuracy.

The damages considered in this section are confined to those capable of definite and accurate estimation in dollars. A summary of the damages estimated is given in Table Ac-3. Damages to river and harbor structures and to the floating plant of the U. S. Engineer Department are based on the years from 1937 to 1939 inclusive and corrected to the year 1940. All other damages are based on average experience during the past ten years and corrected to 1940.

The damages shown on Table Ac-3 for 1940, 1950 and 1960 are all based on 1940 use or on present navigation activity, water supply pumping and other items. The 1960 estimate might well be increased from 25 to 50 percent to include an increment of increased use that is a normal expectancy.

Information for the evaluation of damages by acid mine drainage were collected, in part, during the regular industrial and municipal field investigations and in part by the special staff assigned to the acid mine drainage problem. Knowledge and appreciation of the damages are quite general, but carefully assembled reliable data on the extent of damages in dollars were available in only a small percentage of cases.

However, these relatively few cases were such that unit factors could be determined and applied in other locations with adjustments for the size of the establishment and the severity of the acid problem. Supporting data are too voluminous for inclusion in this supplement. In general, the methods used are as follows:

Water Supplies - Damages to water supplies consist of first, the cost of chemicals required to neutralize the free mineral acids and at least part of the acid salts and, second, the chemicals required to convert noncarbonate hardness caused by acid mine drainage back into its original carbonate form. Lime is needed for domestic, boiler and industrial cooling waters to neutralize the acidity. Soda ash is needed to convert the noncarbonate hardness in the domestic and boiler waters only.

The quantities of water used for domestic and industrial purposes were taken from the field survey reports. Information on raw water quality for the past ten years was obtained from water plant records. Particular emphasis was placed on the records of the McKeesport water plant on Monongahela River water and on the records of the Pittsburgh filter plant at Aspinwall on Allegheny River water.

Neutralization is necessary to prevent corrosion or reduce it to a normal condition that would exist in the absence of acid mine drainage. Neutralization of the free mineral acids or the acidity to methyl orange would leave a water with pH 4.0. This is lower than normal and would still cause excessive corrosion. To raise the pH above 4.0, part of the acid salts must be neutralized. Lime requirements for neutralization have been based on raising the pH to an approximate 7.0 or the neutral point. As the water plant records do not give information directly on the daily quantities of chemical required for this purpose, it has been determined on the basis of long time averages that Monongahela River water at McKeesport above the mouth of Youghiogheny River having a pH of 7.0 will have a methyl orange alkalinity of 14 p.p.m. and a phenolphthalein acidity of 5 p.p.m. Similarly, Allegheny River water at the Pittsburgh intake at Aspinwall having a pH of 7.0 will also have a methyl red alkalinity of 14 p.p.m. Neutralization costs were based on adding sufficient lime to bring the waters up to the alkalinities stated. On days when the alkalinity was above these values it was assumed that no lime was needed.

All of the original acid load as measured by phenolphthalein will be represented by noncarbonate hardness. That part of the acid load neutralized by natural alkalinity will convert carbonate hardness to noncarbonate hardness. That part of the acid load neutralized by lime will also convert the carbonate hardness added by the lime to noncarbonate hardness.

The mean p.p.m. total acid concentration as $CaCO_3$ was computed by applying the original acid loads as given in Table Ac-2 to the average flow in the various streams. As explained, this acid will be represented by noncarbonate hardness and will require soda ash for removal in the domestic and boiler waters.

Steamboats and Barges - River transport equipment suffers slight to severe damage as a result of corrosion of boilers, hulls, pipes, and pumping facilities. Besides corrosion difficulties, scale and sludge formation in boilers, with accompanying poor heat transfer and increased blow-down, and time out of service cause added operating difficulty and expense.

Managers of transportation companies were interviewed and asked for data on damages resulting from acid in the streams. This information was broken down into boiler replacements, boiler cleaning, repairs to hulls, replacements of pumps and pipes, loss of revenue while out of service, and the maintenance of barges. Average cost per boat or barge for the above items was computed. The Pittsburgh office of the U. S. Engineer Department furnished information on the number of boats and barges operating in the district. The annual damages were then computed from the average figures and the numbers of vessels.

Power Plants - The quantities of cooling water used by power plants are very high and neutralization of this water is not practical. In general, water is used without neutralization and equipment is replaced when made necessary by corrosion.

Before making estimates of damages to power plants, many plant superintendents were interviewed and data obtained as to the frequency and cost of replacements and the portion attributable to corrosion. Consideration was given to such factors as average acidity of the water, type of metal used, length of service, time lost by shutdowns and labor costs.

The power plants were grouped by localities and estimates made of damages per unit of capacity for each group. Total damages were then readily computed.

The fact that power plants practice repair and replacement of equipment rather than neutralization of acidity in cooling water is evidence that repair and replacement is the more economical procedure. As a check, the cost to power plants of neutralizing cooling water was computed on the same basis as was the cost to municipal and industrial water supply. Neutralization cost was found to be $261,000 per year as compared to $76,000 for repairs and replacements due to corrosion. This would confirm the wisdom of power plants in not attempting to neutralize cooling water.

River and Harbor Structures - Acid pollution results in damage by corrosion to locks, dams and other appurtenances. This corrosion is accelerated to some extent by the erosive action of the water, which keeps the exposed surfaces clean and damages protective coatings. Since the U. S. Engineer Department is repsonsible for the construction, operation, and maintenance of these structures, the officials concerned were interviewed and asked for an estimate of the annual damages. The figure is based mainly upon experience in regard to average frequency of repairs and replacements.

Floating Plant (U.S.E.D.) - An estimate of damages to their floating plant was furnished by the U. S. Engineer Department.

Other Damges - Damages which are important but for which no detailed estimates have been made include (1) damage to water supply caused by the presence of manganese, (2) damage to recreation through the destruction of normal aquatic life, (3) damage to agricultural uses, (4) damage to highway structures, (5) damage to the mines themselves and (6) the previously mentioned indeterminate but serious damage to the public health.

Manganese is present in acid mine drainage streams but field investigations did not yield information indicating damage of great consequence. Sand filter plants remove the greater part of the manganese without special provisions.

Damage to recreation is an item of great consequence. The Allegheny Reservoir report of the U. S. Engineer Department estimates benefits to recreation from Allegheny Reservoir (reservoir full elevation 1365) equal to $300,000 per year due chiefly to the effect of this reservoir in reducing and eliminating the acidity. Neither the existence nor the magnitude of these benefits, which represent the correction of damages, can be denied but the various methods proposed for the evaluation of recreation facilities are all open to some question.

Damage to agricultural uses include destruction of a water supply used for stock watering or other purposes, damage to inundated land during high water and damage due to destruction of crop growing ability of land by seepage from a mine, as at an outcrop.

Considerable damage results yearly to bridges, culverts, drains and other highway structures from the acid waters. State officials generally agree that acid mine drainage causes considerable added expense each year, but no specific records are available. Replacements have been greatly reduced in recent years by building structures having stone or brick facing and by using a bituminous coated pipe on streams carrying mine drainage.

Damage to the mines themselves is definitely a factor. There are instances of record of a mining company finding it necessary to go a matter of several miles for a satisfactory water supply at the same time that acid water was available in quantity from its mine. In one case, power was purchased even though usable but unmarketable coal was available. An almost universal source of damage is the corrosion of metal work, especially pumps and pipe lines connected with drainage system. A mine may well find it distinctly profitable to seal worked out sections of its active mine in order to decrease damage to pumps, pipe lines and other metal work and to provide an improved water supply. The savings in ventilation have been mentioned.

Some of these damages are capable of evaluation but either time has not been available or expenditures necessary have not been deemed justified. Other damages have not been evaluated either because of the lack of available long-range data or because of the indeterminate nature of the damage.

Although as stated, no estimate has been made of the magnitdue in dollars of the miscellaneous and intangible damages discussed, it may be reasonable to assume that these damages are probably equal to the tangible damages for which estimates have been made.

A clean or unpolluted stream is an extremely difficult item to evaluate. The value depends not only upon monetary considerations which can be estimated with a degree of accuracy but also upon the popular demand and the relative urgency of this demand as compared to other demands upon public and private funds.

An indication of the value of clean streams is shown in the actual expenditures in other areas for the correction of polluted conditions caused by sewage and organic wastes. Statewide averages for pollution abatement programs on tributary streams have been in the neighborhood of from $25,000 to $75,000 per mile of stream improved, the variation depending upon the size of stream, magnitude of the pollution problems and degree of treatment required. Costs on a main stream such as the Ohio River would be much higher than these figures.

Presentation of Laboratory Data

The presentation of the detailed laboratory data collected during the course of the Ohio River Pollution Survey is included in the individual drainage basin presentations to which they apply. These data define the extent of the acid mine drainage problem and show in terms of analytical results the effect of acid mine drainage on Ohio River Basin streams. Figure A-5b and Mo-5a taken from the main volumes of the Final Report of the Ohio River Pollution Survey show the extent of acid mine drainage effects as indicated by pH results on stream water samples on the Allegheny and Monongahela River basins respectively.

In addition to the routine sampling at all important points on the Ohio River Basin, a laboratory unit stationed at Morgantown, West Virginia from late in July, 1940 to the end of June, 1941 performed work relative to the effects of coal mine acid on specific streams. This work is the subject of a separate, special report.

Water Plant Records

The raw water analytical records collected over a period of years by the water plants using river water furnish a valuable source of material for a study of the increasing effect of acid mine drainage during the development of the coal mining industry. With the help of these records, a general long time trend can be established and estimates of future conditions can be made.

As was discussed earlier, if computations of annual average discharges of acid in tons are made, the effect of storage reservoirs that store and release water during the same year is eliminated. Accordingly, water plant records were converted into annual average tons of acidity (or alkalinity) and the results plotted for the period of record. Figures Ac-10 and Ac-11 were prepared in this manner. Mass diagrams of total coal production were plotted on the same graph using a scale selected such that the resulting curve serves as a trend line for the acidity curve. On the Allegheny curve, Figure Ac-10, sulphates are also plotted, since results of this determination were available. Mine acid loads, with expected reductions by sealing, have been plotted on a parallel scale.

Fig. A-5b

ALLEGHENY BASIN

pH RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Fig. Mo-5a

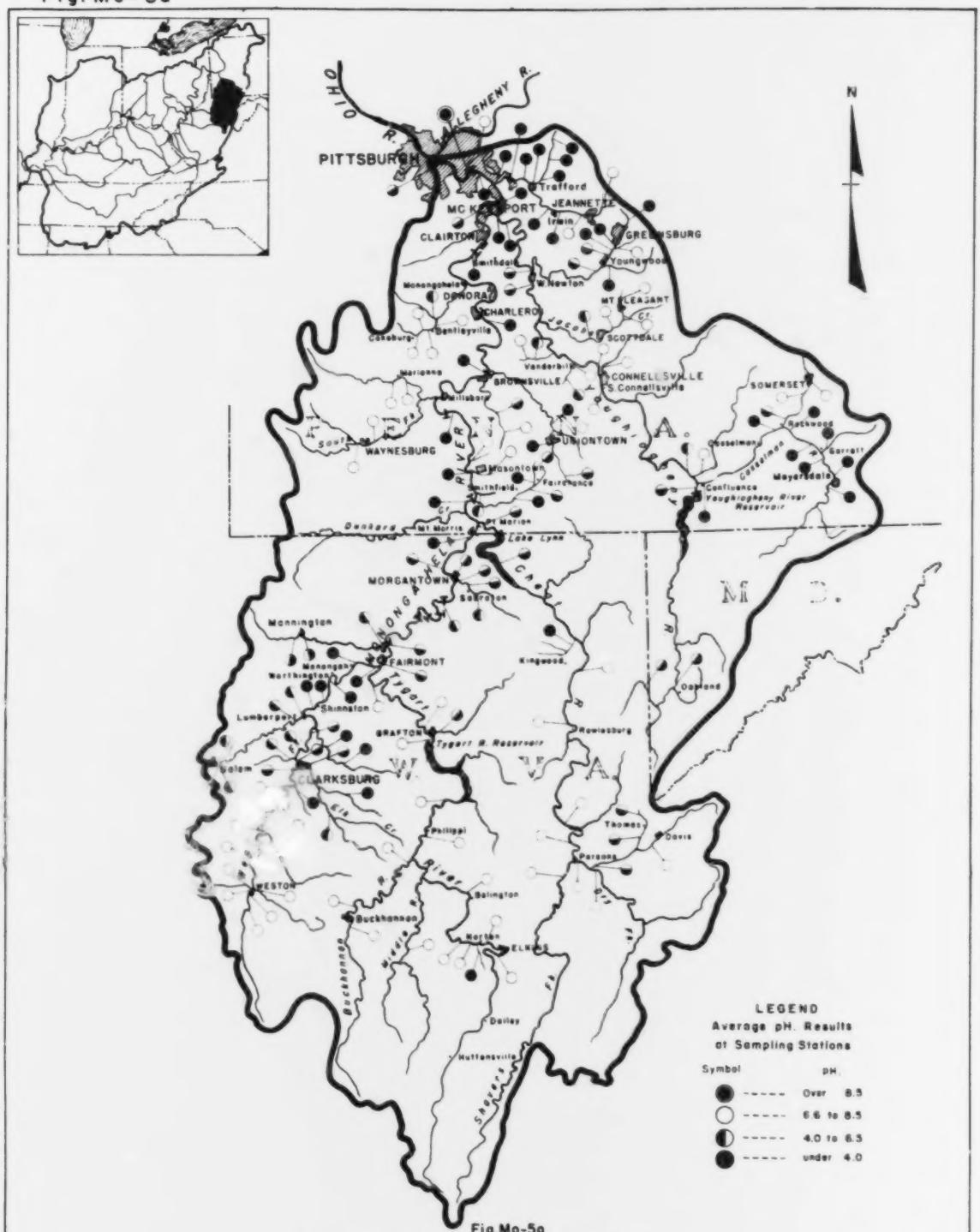


Fig. Mo-5a

MONONGAHELA BASIN

pH. RESULTS

OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941

Discussion

This report has covered the basic theories of acid formation in coal mines and the possibilities and experience with remedial measures. Estimates have been presented of the total acid load, the reduction in this load to date and possible future economical reduction by mine sealing under 1940 restrictions. Costs of this program to date and estimates of future cost are given. Damages have been enumerated, discussed and evaluated.

A consideration which should be mentioned early and kept in mind constantly is that the acid mine drainage problem has been constantly growing and there is little reason to believe that this growth will not continue. The acid mine drainage was no great problem in 1900 but by 1910 it had made itself felt. By 1920 the Kiskiminetas and Youghiogheny Rivers had been acid for some time and the average quality of the Monongahela River above the Youghiogheny was soon to become acid. Since then the problem has become progressively worse and in the high acid year of 1934, the Allegheny River barely missed becoming acid in average quality. By 1955, at the present rate, the Allegheny River may easily have an average acid quality during a normal year.

Damages caused by acid mine drainage have been evaluated for the period from 1930 to 1940. During the next decade, unless corrective measures are actively pursued, these damages will continue their trend upward as the natural alkalinity of the principal streams becomes exhausted. As shown on Table Ac-3, an increase in damages estimated at 50 percent may be expected by 1960.

Remedial Program

A primary purpose of the acid mine drainage study has been to secure basic data on which to base a comprehensive remedial program. The program, as presented, involves mine sealing and flow regulation from storage reservoirs. The program is not the ultimate possible as the mine sealing discussed goes only as far as permitted by 1940 restrictions. However, a large step is involved and upon its completion, additional knowledge should be available in planning further corrective measures.

The studies indicate definitely that the Allegheny River can be brought back to substantially satisfactory condition and this might well be a first objective of a remedial program. Although less detailed studies have been made, it appears likely that many of the headwater streams of the Youghiogheny and Monongahela Rivers can be returned to satisfactory conditions and might well also be included as first objectives.

The Monongahela River above the Youghiogheny River can be greatly improved but, without going somewhat farther than the present restricted program, present indications are that it cannot be brought back to the extent possible on the Allegheny River. There are two reasons for this: first, the original acid intensity in tons per square mile as shown on Table Ac-1 is about four times as great as on the Allegheny River and second, the normal upland water alkalinity (about 10 p.p.m.) is much less than that on the Allegheny River Basin (about 25 p.p.m.). However, against this, the damages caused by acid in the Monongahela River are very high due to extensive use for navigation and water supply and the possible monetary benefits from improvement of the stream are correspondingly greater. Because of this factor, the Monongahela Basin, especially above the Youghiogheny River, is a particularly fitting area on which to concentrate first in carrying out more advanced mine sealing beyond 1940 restrictions.

With the Allegheny River, certain upland streams and finally the Monongahela River above the Youghiogheny River in good condition, it is probable that the main Ohio River will return to satisfactory alkaline quality. Even partial correction of Monongahela River acid, when combined with a satisfactory Allegheny River, might accomplish this objective.

Restoration of the Monongahela River below the mouth of the Youghiogheny River will come much later as it will probably require a substantial alkalinity from above the Youghiogheny River.

There remains the question of the Kiskiminetas and lower Youghiogheny Rivers, where present mining and the acid mine drainage problem are concentrated. Much of the acid comes from active mines. This source is normally the last to be attacked and such attack must be confined to worked-out sections. It is probable that these two stream sections will not be completely returned to satisfactory quality until concentrated active mining moves, at least in part, to other areas.

In summary, it appears that the upper Ohio River and tributaries can best be returned to satisfactory alkaline quality in the following order:

(1) Allegheny River except the Kiskiminetas River
(2) Headwater streams, including the upper Youghiogheny
(3) Monongahela River above the Youghiogheny River
(4) Main Ohio River
(5) Monongahela River below the Youghiogheny River
(6) Lower Youghiogheny River
(7) Kiskiminetas River.

The following discussions of the Allegheny and Monongahela Rivers cover a remedial program involving two types of corrective measures, namely, mine sealing and flow regulation. An estimate of the part each of these measures plays in the total improvement will depend upon which remedial measure is placed in operation first and the first measure will make the more impressive showing.

As a practical approach, the effects of the two remedial measures have been considered on a basis of monthly averages. One effect of reservoir operation will be to reduce or possibly eliminate day-to-day acid surges which create serious water plant operation problems and may render an otherwise satisfactory stream unfit for fish life. Flow regulation benefits, in this respect, will not generally appear in a consideration of monthly averages. Thus one of the important features of flow regulation will not appear as a benefit. Considered from another standpoint, the benefits from mine sealing will be more fully realized if reservoirs for flow regulation are provided.

Conversely, the benefits from reservoir operation may depend, to a large extent, on mine sealing. The Tygart Dam already mentioned, is an example where an acid stream was rendered alkaline, a reservoir was constructed and improvements resulted which no single remedial measure could have accomplished.

This discussion leads to a conclusion that if a complete program involving the two types of control measures is justified, the individual parts are justified. For this reason acid control benefits have been lumped in one figure. This means, in effect, that parts of the mine sealing benefits, as computed from monthly averages, are assigned to flow regulation.

Allegheny River

Records are available on the quality of Allegheny River water at the intake of the Pittsburgh filter plant at Aspinwall from 1909 to date. Average annual alkalinity (to methyl red) and sulphate results in tons and cumulative coal production have been plotted on Figure Ac-11. It is to be noted that the average annual results are subject to wide variations. Several times in the past there apparently have been periods of four or more years during which there has been a definite beneficial trend toward increased alkalinity. Each time there has been a following adverse period so that the general long-time trend has been toward decreased alkalinity.

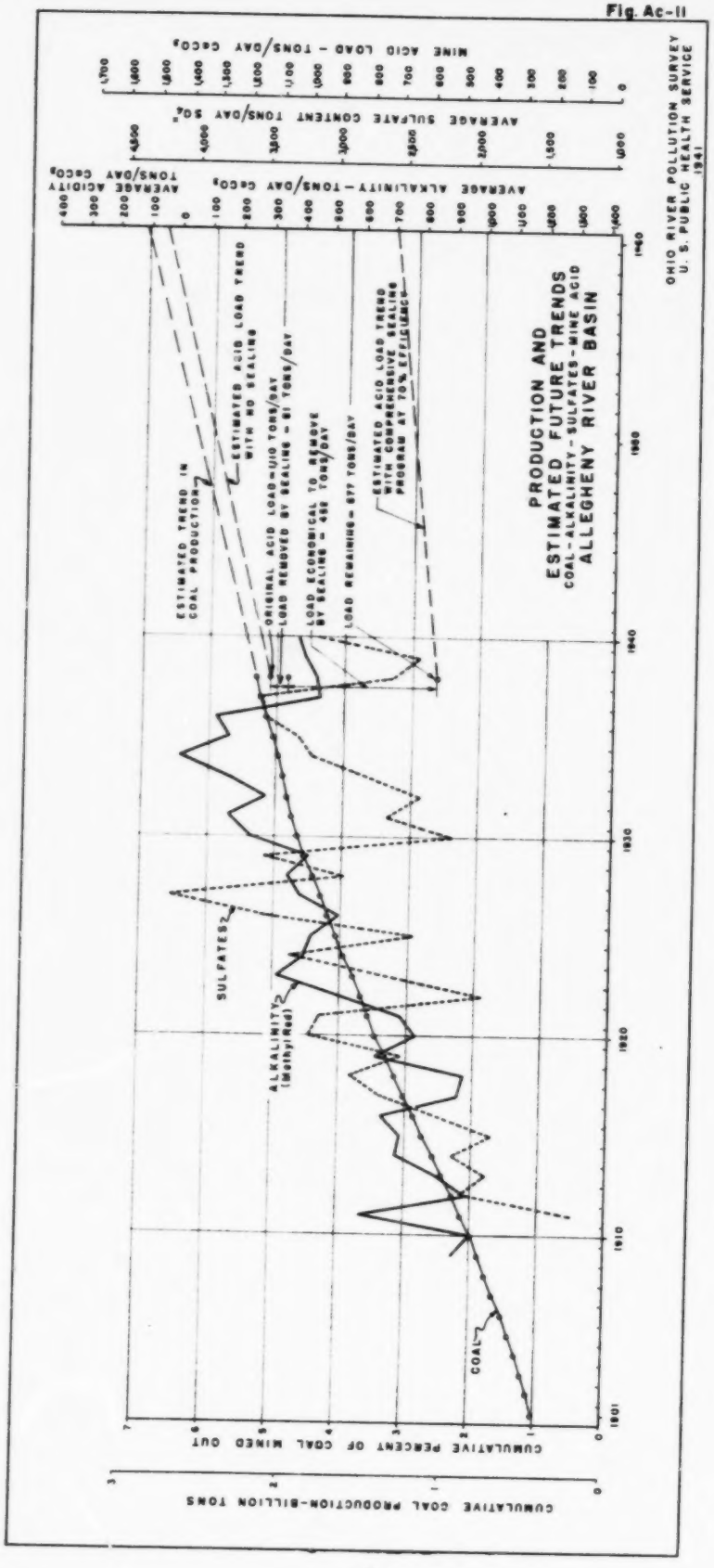
If the curve of cumulative coal production as shown on Figure Ac-11 does, in fact, show the trend of alkalinity and sulphates, the natural alkalinity and sulphate content of Allegheny River water prior to the development of the coal industry were 1400 and 1000 tons per day respectively. The average flow of the Allegheny River at Aspinwall from 1909 to 1940 inclusive was 20,400 c.f.s. Assuming equal distribution of alkalinity and sulphates in the average flow, a natural alkalinity of 25 p.p.m. and natural sulphate content of 18 p.p.m. are indicated.

The average alkalinity of Allegheny River water in 1909 actually was 25 p.p.m. The lowest average annual sulphate result was 36 p.p.m. obtained in 1911, the first year of sulphate record. However, on several occasions average monthly sulphate results of 18 p.p.m. were obtained during the early years of record.

As compared to these old results, the Allegheny River at Aspinwall had an average acidity of 5 p.p.m. in 1934 although in tons, or a weighted average, as plotted on Figure Ac-11, the average quality was alkaline. During that same year sulphates averaged 107 p.p.m. and on seven occasions the average annual sulphates have exceeded 90 p.p.m.

There has been a definite downward trend or an increase in alkalinity since 1934. This year coincided closely with the start of mine sealing activities. While part of the favorable trend may be due to mine sealing activities, there is apparently an additional trend due to a normal cycle followed by the alkalinity curve. In 1934 the average annual alkalinity was 12 tons (to methyl red) per day and the 1940 average was 407 tons per day, an increase of 395 tons per day. Mine sealing records indicate an acid reduction of only 81 tons

Fig. Ac-II


PRODUCTION AND
ESTIMATED FUTURE TRENDS
COAL - ALKALINITY - SULFATES - MINE ACID
ALLEGHENY RIVER BASIN
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941
MINE ACID LOAD - TONS/DAY CaCO3
AVERAGE SULFATE CONTENT TONS/DAY SO4
AVERAGE ALKALINITY - TONS/DAY CaCO3
AVERAGE ACIDITY TONS/DAY CaCO3
CUMULATIVE COAL PRODUCTION-BILLION TONS
CUMULATIVE PERCENT OF COAL MINED OUT
ESTIMATED TREND IN COAL PRODUCTION
ESTIMATED ACID LOAD TREND WITH NO SEALING
ORIGINAL ACID LOAD-1010 TONS/DAY
LOAD REMOVED BY SEALING - 81 TONS/DAY
LOAD ECONOMICAL TO REMOVE BY SEALING - 488 TONS/DAY
LOAD REMAINING - 877 TONS/DAY
ESTIMATED ACID LOAD TREND WITH COMPREHENSIVE SEALING PROGRAM AT 70% EFFICIENCY
SULFATES
ALKALINITY (Methyl Red)
COAL

(to phenolphthalein) per day which would not account for the great increase in alkalinity.

Mine Sealing - A principal purpose of plotting alkalinity, coal production and estimated acid load curves on parallel scales is to serve as a basis for estimating possible accomplishments by mine sealing. The coal production curve appears to be a true trend curve as it parallels lines drawn between successive peaks and successive low points and, in general, follows the course of the alkalinity curve. As the mine acid loads are plotted in parallel, it is not unreasonable to assume that completion of the mine sealing program would drop the trend line to a line representing "estimated acid load trend with comprehensive sealing program of 70 percent efficiency." The ordinate of this latter curve for 1940 approximates the ordinate of the coal production trend line for 1915. This would indicate that a comprehensive sealing program would return the Allegheny River to its 1915 condition.

If all mined-out areas that have developed since 1915 were, in some manner, eliminated as sources of acid pollution, it is to be expected that the acid mine drainage problem would revert to conditions as of that date. A comprehensive mine sealing program is estimated to remove the influence of the equivalent of all mined-out areas developed since 1915. It is, therefore, reasonable to conclude that a comprehensive mine sealing program would return the Allegheny River to its condition in 1915.

The maximum monthly acidity in the Allegheny River in recent years was 23 parts per million. This can be reduced in part by mine sealing and in part by a flow regulation program. The estimated result of the combined program is a conversion of the maximum monthly acidity of 23 parts per million to a minimum monthly alkalinity of 13 parts per million or an improvement of 36 parts per million. On an equitable basis, mine sealing can be credited with an improvement of 22 parts per million in the maximum monthly acidity. Improvement in the average quality would be much less.

Reduction in the Allegheny River acid should result in a lesser but important reduction in Ohio River acidity.

Flow Regulation - The application of mine sealing under 1940 restrictions will greatly reduce the maximum monthly acidity in the Allegheny River but there will still remain

acid surges and months in which conditions are unsatisfactory. The acid surges, particularly during times of low flow, will be a hazard to aquatic life. A further improvement during all but the highest flow months and a measure of protection against acid surges hazardous to aquatic life are possible by the application of flow regulation from reservoir storage.

A flow regulation program is suggested involving storage in a reservoir or reservoirs of 210,000 acre-feet capacity. On an equitable basis, this flow regulation can be credited with a 14 part per million improvement in the maximum monthly acidity, and a lesser improvement in the Ohio River. More stabilized flow will furnish partial protection against acid surges.

The Kiskiminetas River, entering the Allegheny River in its lower reaches, drains a concentrated mining area and is, therefore nearly always acid. Local rains in the area result in serious acid discharges into the Allegheny River and local storage will be required to combat the damages by discharging alkaline water to neutralize the acid surge. Upland storage is of little value in this case as the damage would be done and the danger over by the time water from such storage arrived. Therefore, any reservoir program on the Allegheny River for acid control will require limited local supplementary storage, as behind a local navigation dam provided with proper regulating devices.

The objective and principal features in the operation of the flow control program presented are as follows:

(1) The objective of the program is to maintain, as nearly as possible, a minimum alkalinity of 13 p.p.m. rather than secure the greatest monetary benefits from acid and hardness control. Such an objective tends to protect aquatic life.

(2) Storage is assumed to take place only during months when the alkalinity at Aspinwall is above 13 p.p.m.

(3) The quantity of water assumed to be stored is never such as to reduce the alkalinity at Aspinwall to a concentration below 13 p.p.m.

(4) Unregulated flows are increased as necessary to increase the alkalinity to 13 p.p.m. up to a maximum of the average flow of the stream or 20,400 second-feet.

(5) No attempt is made to increase alkalinity during months when the flow is in excess of the average of 20,400 second-feet. However, no water is stored during such months as such a procedure would further decrease the low alkalinity.

(6) The reservoir or reservoirs are assumed to be emptied each year. This feature and limitation in the amount of water that can be stored under the above restrictions governs the reservoir capacity suggested.

Monongahela River

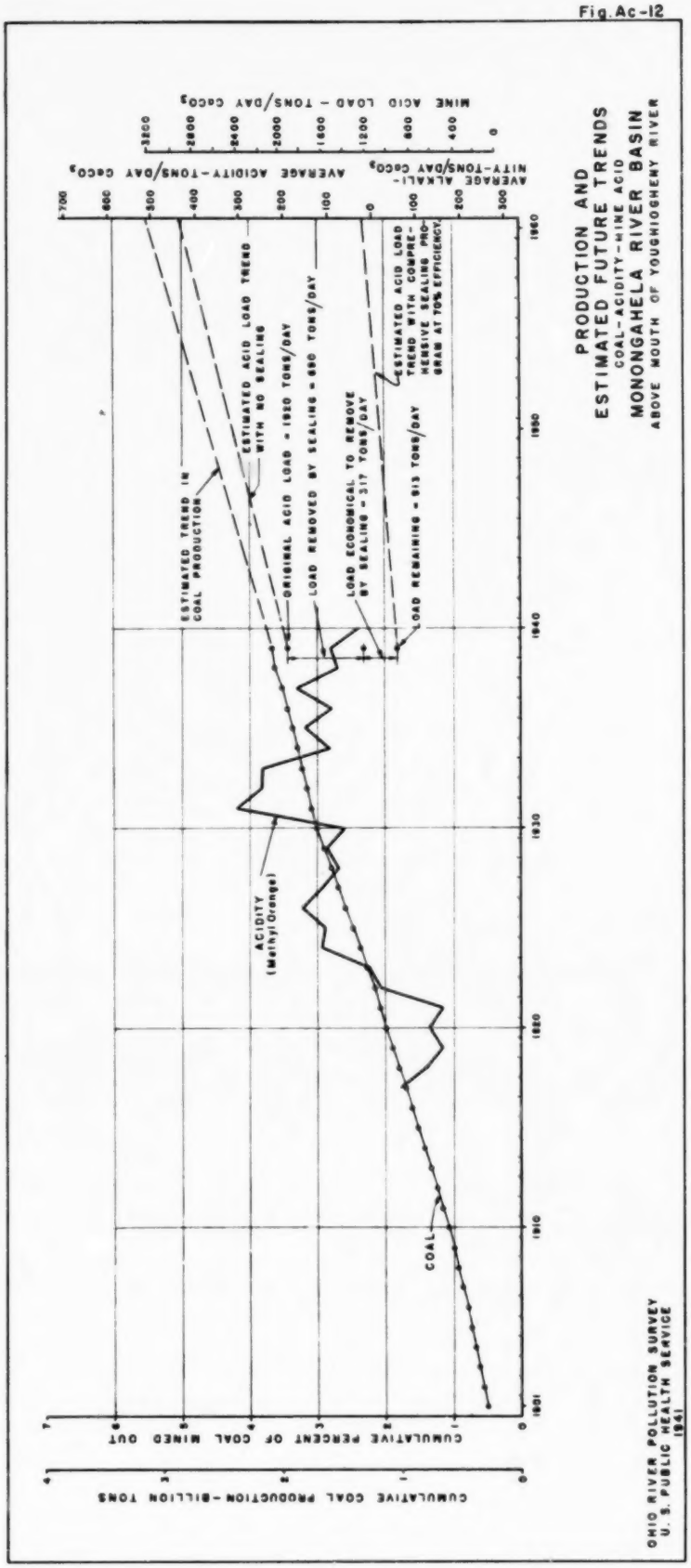
Records are available on the quality of Monongahela River water above the mouth of the Youghiogheny River at the intake of the McKeesport water plant from 1917 to date. Average annual acidity (or alkalinity) results in tons and cumulative coal production have been plotted on Figure Ac-12. As noted on the Allegheny River curve, the average annual acid results are subject to wide variations. However, the general trend, especially prior to the last few years, has been toward an ever increasing acidity.

If the curve of cumulative coal production as shown on Figure Ac-12 does, in fact, show the trend of acidity, the natural alkalinity of Monongahela River water prior to the discharge of acid mine drainage was 300 tons per day. The average flow of the Monongahela River above the Youghiogheny River from 1917 to 1940 inclusive was 10,950 c.f.s. Assuming equal distribution of the alkalinity in the average flow, a natural alkalinity of 10 p.p.m. is indicated. During the early years of analytical record the Monongahela River above McKeesport was alkaline most of the time and as late as 1918 one monthly alkalinity of 8 p.p.m. was recorded.

As compared to this former quality, the Monongahela River above McKeesport had an average annual acidity of 16 p.p.m. in 1930, has had average annual acidities of 10 p.p.m. or more on nine occasions and has had an average quality acid to methyl orange every year since 1922.

During the past decade, or since 1931, there has been a marked decrease in the acid concentration of the Monongahela River. While most of the decrease has been during the comprehensive mine sealing program in the State of West Virginia, it has also been during a period of decreased mining activity, the construction of Tygart Dam and during a normal cycle as indicated by the corresponding Allegheny River curve. It is

Fig. Ac-12


PRODUCTION AND
ESTIMATED FUTURE TRENDS
COAL-ACIDITY-MINE ACID
MONONGAHELA RIVER BASIN
ABOVE MOUTH OF YOUGHIOGHENY RIVER
OHIO RIVER POLLUTION SURVEY
U. S. PUBLIC HEALTH SERVICE
1941
CUMULATIVE COAL PRODUCTION-BILLION TONS
CUMULATIVE PERCENT OF COAL MINED OUT
MINE ACID LOAD - TONS/DAY CaCO3
AVERAGE ACIDITY-TONS/DAY CaCO3
AVERAGE ALKALINITY-TONS/DAY CaCO3
ESTIMATED TREND IN COAL PRODUCTION
ESTIMATED ACID LOAD TREND WITH NO SEALING
ORIGINAL ACID LOAD - 1020 TONS/DAY
LOAD REMOVED BY SEALING - 690 TONS/DAY
LOAD ECONOMICAL TO REMOVE BY SEALING - 517 TONS/DAY
ESTIMATED ACID LOAD TREND WITH COMPREHENSIVE SEALING PROGRAM AT 70% EFFICIENCY
LOAD REMAINING - 513 TONS/DAY
ACIDITY (Methyl Orange)
COAL

undoubtedly true that at least part of the favorable trend is due to mine sealing activities. In 1931, the average annual acidity was 312 tons (to methyl orange) while in 1940 it was 33 tons per day, a reduction of 279 tons per day. Mine sealing records indicate an acid reduction of 690 tons per day but this is measured as phenolphthalein acidity.

Mine Sealing - As is the case of the Allegheny River, the curve on Figure Ac-12 can serve as a basis for estimating possible accomplishments by mine sealing. As a comprehensive mine sealing program is completed, it is assumed that the trend of acid discharge will leave the curve of cumulative coal production and drop to the line representing "estimated acid load trend with comprehensive sealing program at 70 per cent efficiency." There is evidence in the form of the curve that the trend of river water quality, as shown on Figure Ac-12, is already dropping to a line representing residual acid after sealing. However, this cannot be stated with positive assurance on the basis of water plant records for a number of years. Assuming tentatively that the acid trend curve will drop to a curve representing the residual acid load after sealing, it can be concluded that a comprehensive sealing program would return the Monongahela River above McKeesport to the condition it was in 1920. Consideration of the quantity of coal that has been mined out and the magnitude of the comprehensive mine sealing program indicates that this conclusion is reasonable.

The maximum monthly acidity of the Monongahela River, above McKeesport, of 33 p.p.m. can be reduced by mine sealing and flow regulation to an estimated 4 p.p.m. Of this 29 p.p.m. reduction of acidity, 19 p.p.m. can equitably be assigned to mine sealing. Improvement in average quality would be much less. A lesser improvement should also result in the Ohio River.

Flow Regulation - As in the case of the Allegheny River additional improvement is possible by the use of flow regulation from reservoir storage. It is estimated that the use of reservoir capacity totaling 370,000 acre-feet can accomplish a reduction in the maximum monthly acidity equitably estimated at 10 p.p.m.

Objectives and methods of operation are the same as described for the Allegheny River Basin except that flow is increased only up to the average flow of 10,950 second-feet.

Benefits and Costs

The estimated monetary benefits to acid and hardness reduction in the Allegheny, Monongahela and upper Ohio River Basins due to the suggested mine sealing and flow regulation programs total $1,133,000 per year. That this estimate is conservative is indicated by the following considerations:

(1) The estimate is based on 1940 damages whereas Table Ac-3, page 9 , indicates that estimated damages may increase 50 percent in the next 20 years.

(2) The estimate is based on a program of mine sealing under 1940 restrictions. A more complete sealing program could reduce the residual acid load an estimated further 50 percent and should yield much greater benefits. Costs would be higher but not in proportion to the increased benefits.

(3) The estimate does not include benefits to: (a) decreased manganese in water supplies, (b) recreation, (c) agricultural uses, (d) highway structures, (e) the mines themselves or (f) indeterminate benefits to the public health. These damages might reasonably be considered to equal the estimated monetary damages.

The estimated cost of the restricted mine sealing program considered is $3,250,000. Annual charges of interest (3½%), amortization (0.7 or 3½% for 50 years), inspections (2%) and maintenance (7 to 10%) are about 15 percent or $488,000 on this additional expenditure. Similar annual charges on existing mine seals of 15 percent of the approximately $2,550,000 spent on mine sealing to date in this area are $382,000, making a total cost of $870,000 per year. As shown on Figure Ac-3, page 6 . if these existing seals are not maintained, the benefits already realized may easily be lost, making it necessary to repeat the expenditure.

If the remedial program is considered as a whole, this annual cost deducted from the total benefits would leave $263,000 for expenditures for flow regulation. While this allocation of benefits is not unreasonable, it probably does not do full justice to mine sealing which, if taken alone, will amply justify itself from a monetary benefit standpoint.

Additional benefits because of organic pollution abatement are also available to flow regulation.

Organic Pollution Abatement

Organic pollution in the upper Main Ohio River can be controlled satisfactorily by a partial treatment of sewage and industrial wastes plus flow control adequate to eliminate those low-flow periods when a higher degree of treatment would normally be required. A second method of control would be to allow natural flows to remain unchanged and install facilities for providing the required higher degree of treatment.

In estimating the value of flow regulation for organic pollution abatement, this value was considered as equal to the difference in cost between partial treatment and the required higher degree of treatment.

The required flow has been estimated to be 8,000 c.f.s. during the warm summer months (25°C. or 77°F. average monthly air temperature) and lesser flows during the colder months. With this flow regulation, primary treatment plus equivalent treatment of industrial wastes would be adequate to maintain satisfactory stream conditions for reasonable use other than domestic water supply immediately below Pittsburgh.

The question arises as to the justification of attempting to maintain such conditions during times of abnormally low flow such as occurred during 1930. Conditions of 1930 have occurred but once in a period of record of over 30 years and have not been approached in any other year. If 1930 is included, storage required for flow regulation is 830,000 acre-feet while during all other years storage of 430,000 acre-feet would be adequate. It is concluded that the cost of providing the higher storage capacity is greater than warranted by control of pollution during a drouth occurring but once in 30 years. This does not mean that conditions would not be improved during an extreme drouth. A valuable partial organic pollution control would be available even during a year such as 1930.

Without flow regulation a higher degree of treatment (estimated as effective chemical treatment) would be required to maintain equivalent stream conditions. Estimated additional annual costs of the selected chemical treatment over primary treatment is $300,000 at Pittsburgh. Flow regulation above Pittsburgh would increase the minimum flow at Cincinnati and this increase would result in savings for similar reasons of an additional $300,000.

While the flow regulation is designed primarily for acid pollution control, minor adjustments in the operating schedule make it possible for the flow regulation also to serve as a

valuable aid in organic pollution control. The two flow regulation objectives fit well together as acid discharges are at a minimum during dry periods when augmented flow is required for organic pollution control. An examination of flow and acidity records indicates that acid control and organic pollution abatement can both be accomplished with the exception of one month (also excepting 1930) in ten years and this accomplishment has been taken as satisfactory.

Storage required for organic pollution abatement is 430,000 acre-feet (except in 1930) while flow required for acid control is 210,000 acre-feet in the Allegheny River Basin and 370,000 acre-feet in the Monongahela River Basin or a total of 580,000 acre-feet. This last storage figure of 580,000 acre-feet has been used in estimating benefits.

Annual benefits to flow regulation include $263,000 left after deducting mine sealing costs from acid and hardness control benefits, plus $300,000 for organic pollution control at Pittsburgh and $300,000 for organic pollution control benefits at Cincinnati, making a total of $863,000 per year. As the storage required is 570,000 acre-feet, the annual benefits computed are about $1.49 per acre-foot.

Studies conducted by the Corps of Engineers disclose that storage capacity can be provided in the quantities required for low-flow control in the Allegheny-Monongahela-Upper Ohio River Basin. It is further indicated that the best development of the water resources of the basin would provide low-flow control as a function of multiple-purpose reservoir operation. Under such circumstances, the average annual benefits which could be reasonably assigned to such an improvement would be in excess of the average annual cost.

The essential features of the acid and organic pollution control program on the upper Ohio River Basin is shown in the "Summary for Main Report" which is also included in the first part of this supplement.

Personnel

The acid mine drainage studies, with the exception of laboratory activities, were carried out under the administrative direction of Senior Sanitary Engineer H. R. Crohurst, in charge of the Office of Stream Sanitation. The work was organized and carried out under the general direction of Sanitary Engineer (R) Ellis S. Tisdale and under the immediate supervision of Senior Public Health Engineer M. LeBosquet, Jr. A field office was established in the Office of Mine Sealing of the U. S. Public Health Service, Regional Consultant E. W. Lyon in charge. This field office for the Chio River Pollution Survey was placed in charge of Assistant Sanitary Engineer (R) Paul D. Haney. Assistant Sanitary Engineer (R) Ralph C. Palange and Assistant Chemical Engineer Royal E. Rostenbach were assigned to assist in the work.

Laboratory activities were performed under the administrative direction of Senior Sanitary Engineer J. K. Hoskins, in charge of the Stream Pollution Investigations Station, succeeded in July, 1940, by Medical Director H. E. Hasseltine. Technical direction of the work was by Senior Sanitary Engineer H. W. Streeter. Passed Assistant Sanitary Engineer (R) C. L. Chapman was in charge of special acid stream work at Morgantown, W. Va.

Estimates of accomplishments and financial benefits of acid control measures were prepared in the Cincinnati office, and the final Supplement "C" is the joint work of Messrs. LeBosquet and Haney with assistance in the preparation of estimates by Mr. Palange.

The supplement was reviewed by Mr. Lyon, R. D. Leitch, Chemical Engineer of the Bureau of Mines, Pennsylvania officials and others. Valuable contributions were made in these reviews.